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THE MECHANICAL PROPERTIES OF WELDED JOINTS

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The material deposited from a welding rod must as far as possible possess the same mechanical properties as the material of which the pieces to be welded consist. The Philips welding rod type 55 was especially intended for welding the steel St 52; consequently a tensile strength of at least 52 kg/mm^2 was required of the material deposited in the weld. By a suitable choice of the necessary hardening components the high tensile strength could be obtained without a detrimental increase of hardness in the weld and without diminishing the deformability. The high notched bar toughness of the material deposited is very striking (17 to 20 kgm/cm^2 for a cross section of the break of 5×10 mm^2). This is obtained by a suitable composition of the coating of the welding rod, whereby the nitrogen which depresses the impact value, is prevented from reaching the deposited material. Thanks to the great toughness and deformability (plastic reserve) of the deposited material of the Philips welding rod 55, very hard types of steel, rich in carbon can also be welded, while on the other hand due to the calcium content of the coating it is also possible to weld types of steel of poorer quality contaminated with sulphur. Even free-cutting steel which is very rich in sulphur can be welded with these rods without the occurrence of porosity.

In arc welding the joint between two plates is obtained due to the fact that the heat of the arc fuses not only the welding rod serving as electrode but also a surface layer of the plates, and causes the materials to run together. During this process, in the fused material, on its surface and in the transition zone to the parent metal of the plates, all kinds of chemical reactions take place which may exert a far-reaching effect on the mechanical properties of the finished weld. If certain properties are desired the processes taking place must be controlled in a suitable way. Four main factors may be indicated which are hereby important: the composition of the parent metal, the composition of the welding rod, the environment in which the fused material is situated (coating of the rod) and the rate of cooling.

The first of these factors is not generally under control, since the choice of the parent metal will be determined by other, particularly structural considerations. The second and third factors are the ones which the manufacturer of welding rods can vary in order to adapt his product to the requirements of the constructor. The fourth factor is mainly a question of welding technique.

What are the requirements of the constructor? The mechanical properties of the welded joint must correspond as nearly as possible with those of the parent metal. This generalized formulation of the requirements is by no means obvious. Formerly it was as a rule considered sufficient when the tensile strength of the weld (the material deposited) was the same as that of the parent metal; at present the conclusion has been reached that the other mechanical properties also, such as the elongation, notched bar toughness, etc. should satisfy the same requirements.

From the above it follows that the better the quality of the material to be welded, the higher the requirements which should be made of the welding rod. The opposite is, however, also correct up to a certain point: it is more difficult to obtain a satisfactory weld, the poorer the quality of the parent metal, *i.e.* the more impurities contained in it (sulphur, phosphorus, etc.) which are detrimental to certain mechanical properties (sometimes to the advantage of others). These impurities may for instance cause very unpleasant phenomena upon welding, such as the occurrence of porous spots or cracks in the weld.

A new welding rod has recently been developed by Philips (type 55) with the intention of satisfying different requirements simultaneously. The rod is on the one hand suitable for welding good qualities of steel (St 52), and this in the sense that the material deposited from the rod not only has the same high tensile strength as the steel, but also among other properties an unusually high impact value; on the other hand the welding rod is extremely insensitive to the most dangerous component of the parent metal, namely sulphur. In the following we shall discuss these properties more closely and indicate their relation to the above-mentioned factors under the control of the manufacturer: the choice of composition and coating of the welding rod.

The tensile strength of the weld

In the early days of arc welding only the ordinary kinds of ingot steel, for instance St 37 (*i.e.* a steel with a minimum tensile strength of 37 kg/mm^2) were welded. Only about 10 years ago the kinds of steel with a higher tensile strength, among which St 52 is the most important representative, began also to be welded electrically. In Germany several bridges were constructed of welded St 52. The result was at first disappointing: in some of the welded girders cracks appeared, a phenomenon which had never been encountered with St 37. What was the cause?

The difference between the tensile strength of St 37 and St 52 is due to the difference in the contents of so-called hardening elements, carbon among others. If iron containing carbon is cooled rapidly from the high temperature necessary for the preparation of the steel, it is very hard, which also means that it has a high tensile strength and yield value, since the latter are correlated with each other and with the hardness. The greater the speed of cooling, the greater the hardness caused by the carbon.

The process of hardening is now as it were repeated during the welding, and this takes place in different ways at different spots in the weld. The hardening is most pronounced in the transition zone between weld and parent metal, since here part of the latter is heated during the welding to just under its melting point and then very rapidly cooled, due to the good heat conduction of the parent metal. This cooling is considerably more rapid than was the case in the preparation of the material (for instance 50° per second). The result is an increase of hardness in the transition zone. This increase in hardness, which depends further upon the percentage of carbon, and which may often amount to a factor 2, is accompanied by a decrease in the deformability. When the welded structure is loaded, therefore, any deformation will have to be taken up to a greater degree by adjacent parts, so that an elongation may here occur beyond that which is permissible.

When it was finally understood that one of the most important causes of disappointments in the welding of St 52 was due to this phenomenon, the remedy was immediately obvious: the carbon used to obtain the high tensile strength of the steel should, at least partially, be replaced by other hardening elements whose action upon more rapid cooling did not, or not to that degree, increase. Manganese, chromium, silicon, copper, etc. may be considered. These elements, if present in too large quantities, may also have detrimental effects on the behaviour of the steel, so that it was necessary to establish maximum percentages, on the basis of experience, in which the hardening elements may be present in the steel St 52. These percentages are given in *table I*[1]).

Table I

Permissible percentages of different hardening elements in St 52 1), and percentages of the same elements in the material deposited from the Philips welding rod 52.

	St 52	Philips 55
carbon	0.20%	0.07%
manganese	1.50μ)	0.90
silicon	0.50	0.30
copper	0.55	0.30
phosphorus	0.06	0.02
sulphur	0.06	0.02

*) 0.30% manganese may also be replaced by 0.40% chromium or 0.20% molybdenum.

These considerations, which until now have referred only to the parent metal, are also of importance for the welding rod itself. The iron of the welding rod with which we wish to weld St 52 must of course be provided with hardening components in order to obtain the desired high tensile strength (at least 52 kg/mm^2). At the same time, however, in the most rapidly cooling parts of the weld the hardness must not be too great, so that the carbon content must be limited.

In the composition of the welding rod type 55 particular attention has been paid to the permissible limits for the proportions of the various hardening components. The values given in the second column of table I indicate that the deposited material of the rod remains far below the limits prescribed for St 52 itself [2]). Nevertheless the tensile strength is more than sufficient. In order to determine this a weld is made between two plates of St 52, and from this a flat test piece is made with the weld in the middle, see *fig. 1*. The tensile test gave a tensile strength of 55—57 kg/mm^2.

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[1]) Specifications of the German railways.

[2]) The relativity high content of copper is favourable for the corrosion resistance of the weld.

The tensile strength still depends to a certain degree upon the conditions during welding. In the test just mentioned the plates of St 52 steel were welded "horizontally", *i.e.* the bead lay horizontal. In "vertical" welding, beginning at the bottom and working upwards, the same test gave a somewhat higher value of the tensile strength, namely 59 kg/mm^2. If a weld is laid in a gutter of fairly thin sheet, and the weld metal thus obtained is turned to give round test pieces (fig. 1), lower values of the tensile strength are found. This is indeed quite understandable, since in this case the heat cannot flow away rapidly during the welding, so that the weld metal cools only slowly and is as it were annealed. With the Philips welding rod 55 a tensile strength of 48—52 kg/mm^2 was found with such rods and a yield value of 38—51 kg/mm^2. In fig. 1 it may also be seen that the weld metal possesses an unusually great deformability: the elongation at rupture (measured on a length 5 times the diameter) amounts to 35—40 per cent, while a constriction of 74—80 per cent occurs. This great elongation and constriction, which offer a guarantee that the welded structure can be considerably deformed due to strains without breaking (so-called plastic reserve of the construction) are due largely to the same measures as were taken to increase the notched bar toughness of the Philips rod 55. We shall discuss this in the following.

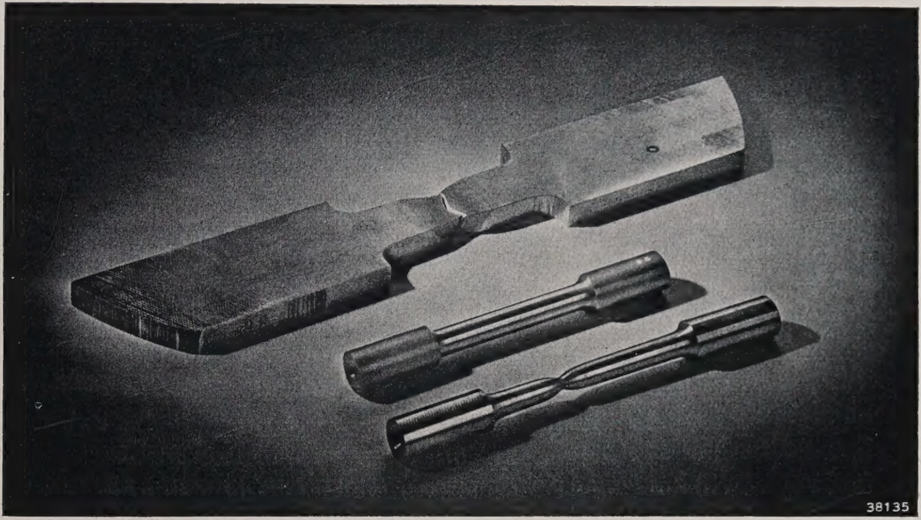

Fig. 1. Flat test piece for testing tensile strength made from a weld with the Philips welding rod 55 between two plates of St 52; the tensile strength of the steel was somewhat high, namely 60 kg/mm. Due to this the break occurred in the weld itself, as was desired, and not outside it. The round test pieces are made entirely of fused weld metal. The great elongation and pronounced constriction of the broken rods is striking.

The notched bar toughness of the weld

While the values of the tensile strength and yield value indicate only the maximum, or a point of the stress-strain diagram of special importance to the constructor, the value of the notched bar toughness gives a sort of integral over such a diagram, namely the total work which must be done by the deforming force in order to break the test rod into two pieces. This work is of especial importance for those cases where the deformations are concentrated at a single point of the piece of work, since then the rest of the piece does not as it were collaborate in taking up the work of deformation. Such a concentration (local increase of stress) occurs regularly at more or less sharp notches (this is the reason for the notching test), at transitions from this to thick cross section, etc.

In welds also such increases in stress will often occur, and it is therefore quite justifiable to require a high notched bar toughness for the deposited weld metal.

The notched bar toughness of a steel is found to be influenced to the highest degree by its content of nitrogen, as *fig. 2* shows 3)). The relation is of

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3)) Fig. 2 is borrowed from W. Bisehof and W. Püngel, Z. Westfälische Union Augustus 1939, p. 13. As to its general shape, the curve agrees with observations of others, for instance D. Séférian, Diss. Paris, 1935, whose results have already been discussed by J. Sack in this periodical (Philips techn. Rev. **2**, 129, 1937).

course not always the same, the further chemical composition also plays a part. Nevertheless the general conclusion is certainly correct that with increasing content of nitrogen the notched bar toughness decreases. Good qualities of steel thus contain only little nitrogen. In welding, however, there is a danger that nitrogen in atomic form will be taken up from the air (at the high temperature of the welding arc the air is for the most part dissociated into atomic oxygen and nitrogen). Combatting this is one of the most important functions of the coating of the welding rod. In the first place this coating forms a more or less sealing layer of slag on the fused iron. Furthermore the coating can be so composed that upon heating it develops large amounts of gases, harmless in themselves, which form a protecting atmosphere around the fused material. Especially organic components, such as starch, sawdust etc. are used for this purpose. In the case of the rod type 55 a different method has been chosen to reinforce the nitrogen resisting action of the coating, namely the addition of substances which are able to form a chemical compound with the nitrogen (and also with oxygen). Thanks to these measures the percentage of nitrogen in the deposited weld metal could be reduced to the very low value of 0.01 per cent. For the sake of comparison the nitrogen content of several other common kinds of welding rods is given in *table II*. At the same time it may be seen that the expected strong increase in the notched bar toughness runs parallel to the decrease in the nitrogen content; in the case of the Philips rod 55 the former amounts to 17 to 20 kgm/cm^2 on a cross section to be broken of 5×10 mm^2, and 73 to 26 kgm/cm^2 on a cross section of 2×10 mm^2.

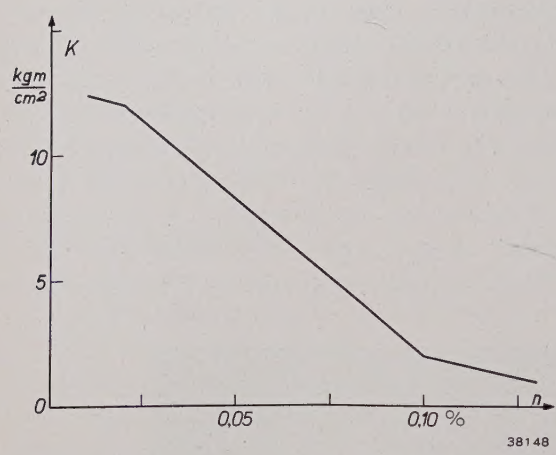

Fig. 2. Variation of the notched bar toughness *k* as a function of the nitrogen content *n* in per cent by weight [3]).

Table II

Nitrogen content and notched bar toughness of the deposited material of different kinds of welding rods.

Type of welding rod	Nitrogen content in %	Notched bar toughness (5×10) in kgm/cm^2
Uncoated rod	0.15	1
Medium thickly coated rod	0.07	4
Thickly coated normal quality rod	0.035	10
Medium thickly coated rod with partly organic coating	0.0125	11
Thickly coated rod Philips 55	0.010	18

The values of the notched bar toughness mentioned are measured on impact test pieces which were prepared as shown in *fig. 3* from the welded joint. The notch is in this case so far away from the parent metal that the latter has no effect on the result. The good reproducibility of the impact test is striking. *fig. 4* shows a series of 12 rods with a cross section of 5×10 mm^2 which have been subjected to the impact test. Their notched bar toughness or impact value was found not to vary more than from 17.2 to 10.5 kgm/cm^2.

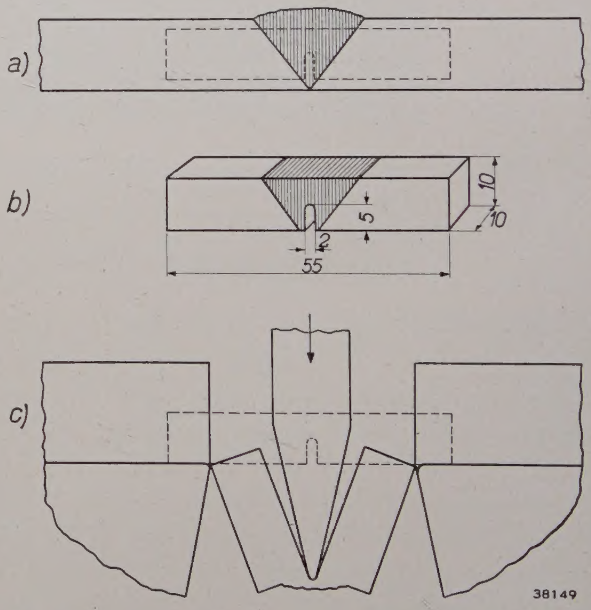

Fig. 3. The way in which the test pieces (*b*) are made for the impact test (*c*) from a weld (*a*). The deposited weld metal is shaded.

In giving these values it must also be mentioned that they are obtained at room temperature (about 20° C). In contrast to all other properties of materials of interest to the constructor, the notched bar toughness is very closely dependent upon the temperature, and this dependence is similar for all kinds of steel: there is a pronounced minimum at 400—500 °C and a rapid fall at temperatures below the zero point. The significance of this sharp fall in notched bar toughness at low temperatures (the so-called cold brittleness) was formerly often not sufficiently realized. It has been one of the causes of various accidents in which welded bridges have developed cracks during very cold weather [4]). If one compares the variation of the notched bar toughness for the material deposited from the welding rod 55 with the curve for a normal good quality welding rod, *fig. 5*, it may be seen that the much higher value of this toughness has as it were shifted the curve as a whole to higher values. While in the case of the ordinary welding rod the notched bar toughness decreases from 11 kgm/cm² at 20° to 6 kgm/cm² at —50 °C, in the case of the Philips rod 55 the notched bar toughness at —50° C still has a value of about 14 kgm/cm². Only at still lower temperatures, which, however, do not occur in inhabited parts of the world, would the notched bar toughness fall to dangerously low values.

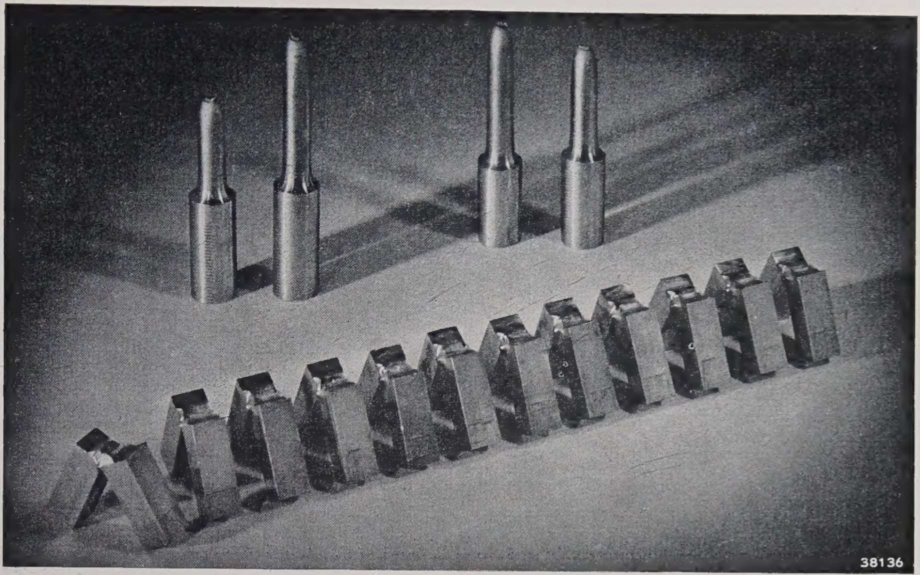

Fig. 4. Series of 12 test pieces made from welds with the Philips welding rod 55 to which the impact test has been applied. The results are seen to be satisfactorily reproducible. The pieces are not broken through, but bent down between the supporting blocks by the impact. In order therefore to obtain the correct impact toughness a small (unknown) amount of work which would be necessary to separate entirely the two halves of the test piece must still be added.

In other respects also besides temperature, the notched bar toughness is a particularly "sensitive" property of materials. In the heat treatment to which welded constructions are sometimes subjected in order to remove stresses occurring as a result of the welding, the notched bar toughness of some kinds of welding rods is found to decrease enormously, even to $^1/_{10}$ the original value, while other properties, such as tensile strength and elongation, exhibit only relatively small changes which are quite in line with the expectations. Such a great decrease in the notched bar toughness must be ascribed mainly to a too large percentage of nitrogen in the rapidly cooled weld metal [5]). The nitrogen

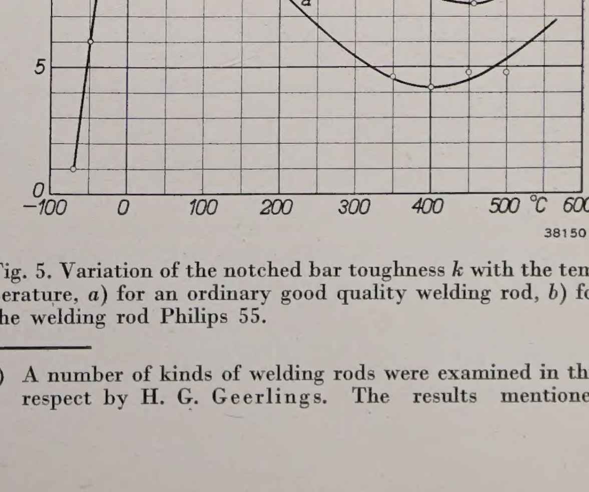

Fig. 5. Variation of the notched bar toughness *k* with the temperature, *a*) for an ordinary good quality welding rod, *b*) for the welding rod Philips 55.

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[4]) This was the case of the bridge of the Reichsautobahn at Rudersdorf and the two bridges at Herenthals and Kaulille over the Albert Canal.

[5]) A number of kinds of welding rods were examined in this respect by H. G. Geerlings. The results mentioned

is separated out on the crystal boundaries in the form of Fe_4N upon reheating, and this produced a more brittle material. In agreement with this explanation is the fact that this effect is very small when the welding is done with the Philips rod 55, where the weld metal contains very little nitrogen. Even after the so-called normalizing annealing (at 920° C) the original high value of the notched bar toughness is still measured.

The separation of nitrogen mentioned above also takes place at room temperature, although extremely slowly. The so-called ageing of the weld metal must be ascribed to this phenomenon (among other factors). Since experiments in this direction would have to extend over a very long period, an artificial ageing test is usually applied for judging materials in this respect. By stretching the material (10 per cent) and then annealing it ($^1/_2$ hour at 250 °C) a kind of accelerated ageing is obtained. In the case of the weld metal of the rod 55 this was found to cause only a slight decrease in the notched bar toughness, namely from 17.7 to 13.5 kgm/cm^2, while for a normal good quality welding rod a decrease from 10.4 to 4.5 kgm/cm^2 was found.

In order to complete the picture of the properties of the Philips welding rod 55, it may be mentioned that the fatigue bending strength (load necessary for breakage after 5×10^6 alternations) amounts to 26—28 kg/mm^2, a value in the neighbourhood of that for St 52; furthermore that the welds can easily be forged and that the bending test also gives good results. Several rods which were subjected to the latter test are shown in *fig. 6*, the text beneath the figure gives further details.

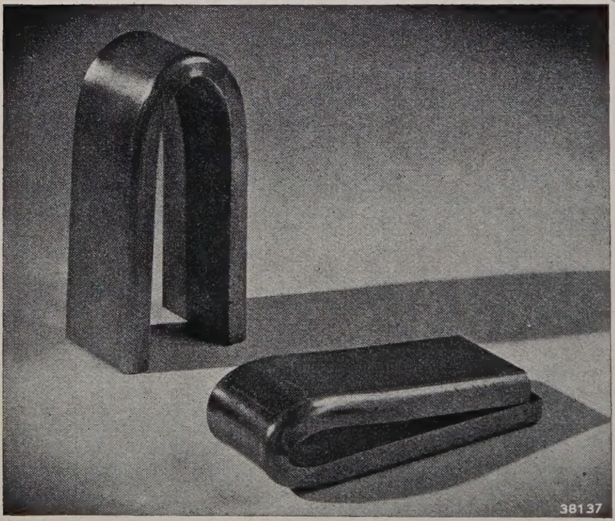

Fig. 6. A commonly applied method of testing welded joints is the bending test. A test piece with the weld at its middle is bent over a mandrel of a given diameter until cracks occur. The test pieces here shown are 10 mm. thick and made of St 52 welded in a V-weld with the Philips rod 55 and bent over a mandrel of 30 mm diameter. With a bending angle of 180° the weld is still intact, even in the test piece in the foreground which was flattened after being bent.

The welding of "difficult" types of steel

While in the above it was assumed that the deposited weld metal must be the equal in properties of the parent metal, cases also exist in which this requirement is unnecessary, and where nevertheless difficulties are experienced in welding. If for example one tries to weld special kinds of steel such as StC 45 (a very hard steel with a carbon content of 0.45 per cent), StC 60, etc. with an ordinary good quality welding rod, aftercooling cracks often appear in the weld. Upon closer consideration this is not strange. Aside from the great increase in hardness in the transition zone, which is caused by the high carbon content of the basic material, the latter of itself is already so hard and little deformable that even upon shrinking during cooling very high requirements are made of the deformability of the weld metal. Thanks to the great toughness and the considerable plastic reserve of the material deposited by the Philips rod 55, it is also possible to weld the difficult, very hard steels with this rod. This is demonstrated by *fig. 7*, while in *figs. 8* and *9* a practical example is reproduced where use has been made of the possibility mentioned. In the cast steel head of a heavy press (300 tons pressing force) a 50 mm thick reinforcing plate of St 37 had to be welded. In spite of the high carbon content of the cast steel (0.60 per cent) and the large dimensions of the parts to be welded, a weld which was free of cracks could be obtained. In order to limit the speed of cooling the head of the press was heated to 125 °C before welding.

Another kind of difficulty which may occur in welding is the formation of gas bubbles in the transition zone, usually to be ascribed to impurities in the layer of the parent metal which becomes mixed with the fused weld metal. If these gases are liberated at an unfavourable moment, namely during the solidification of the material, they can under certain circumstances no longer escape, or the fused material can no longer fill up the cavities, and a porous weld is obtained with cavities and craters. It is unnecessary to state that this is very detrimental to the mechanical properties of the

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here were published by him in Laschsymposium 1940-1941, p. 13. It must be mentioned that the oxygen also plays a part in the decrease in notched bar toughness, and that there is almost always 2 to 3 times as much oxygen as nitrogen in the material fused. Much less, however, is known about the part played by the oxygen than that of the nitrogen.

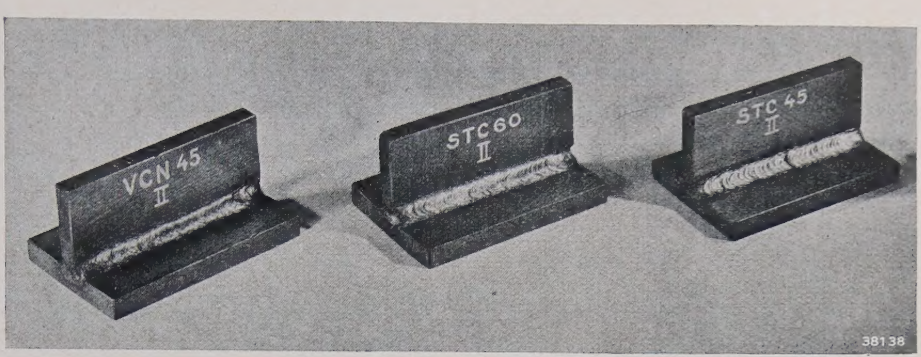

Fig. 7. Fillet welds on three different kinds of very hard steel. The welds are made with the Philips rod 55 according to a standardized method of the German railways for testing for freedom from cracks. Except for a single very small crater crack no cracks were found in any of the three welds reproduced here.

welded joint, especially because cracks may develop from the cavities.

It has been found by experience that too large a content of sulphur in the parent metal must often be held responsible for this formation of gases and the resulting porosity [6]). It is known from metallurgy that in the Siemens-Martin process a removal of sulphur from the iron is obtained by means of lime in a reducing environment. The sulphur is then for the most part bound by the calcium; for which the following reaction may be accepted:

$$FeS + CaO + C \rightarrow Fe + CaS + CO.$$

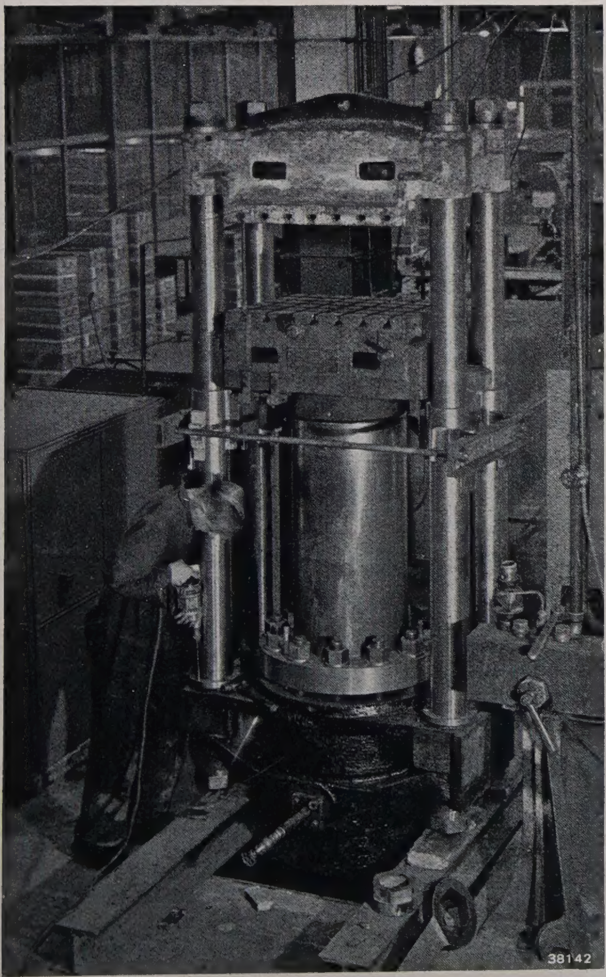

Fig. 8. Press with 300 tons pressing force during assembly. In the head of the press a reinforcing plate 50 mm thick has been welded with the Philips rod 55. The head is of cast steel (0.60 per cent carbon), the reinforcing plate of St 37.

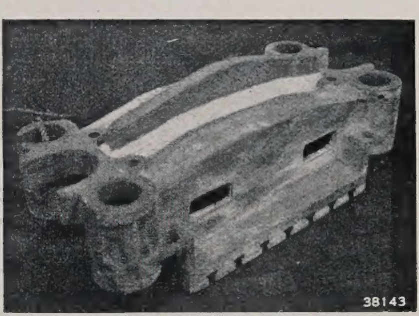

Fig. 9. Head of the press of fig. 8 with welded reinforcing plate.

The calcium sulphide formed, in contrast to the iron sulphide, is entirely taken up in the slag, and the sulphur content of the steel is thus decreased. The coating of the Philips rod 55 is also composed on a lime basis, so that in the fused material, which is in intimate contact with the slag, a binding of any sulphur present in the basic material can take place. This was well illustrated in a test in which a steel poor in sulphur and one rich in sulphur (0.03 and 0.23 per cent, respectively) were welded with the Philips rod 55, while afterwards the slag was chemically analysed. In the second case the slag was found to contain 2 to 3 times as much suphur as in the first. The fact that the Philips welding rod 55 is indeed very insensitive to sulphur is clearly shown by *fig. 10* where fillet welds are shown which were laid on a steel with much sulphur (0.09 per cent) with the Philips rod 55 and with an ordinary good welding rod, which was, however, sensitive to sulphur. The difference is even more pronounced when one attempts to weld free-cutting steel. This steel contains very much sulphur in the form of FeS, to which its easy machinability is due, and which makes it suitable for machining in automatic lathes, etc. *Fig. 11* shows a fillet weld in free-cutting steel with 0.23 per cent of sulphur (and in addition 0.08 per cent of phosphorus), the right-hand half of which is welded with an ordinary good quality welding rod and the left-hand half with the Philips 55. The latter half is absolutely tight, and, as shown by stretching and bending test, mechanically quite satisfactory, while the weld obtained with an ordinary rod is quite porous and mechanically useless. It is therefore possible to state without exaggeration that with the Philips welding rod 55 types of steel can be welded which have been characterized as unweldable up to the present.

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[6]) An important example from practice may be found in L. Reeve, Trans. Inst. Welding **3**, 11, 1940. A report is here given on the case of the bridge near Hasselt (Belgium) which collapsed several years ago. Photographs of preparations made from the welded points of this bridge show gas cavities at spots immediately adjacent to the parent metal which contained 0.095 and 0.063 per cent of sulphur, respectively.

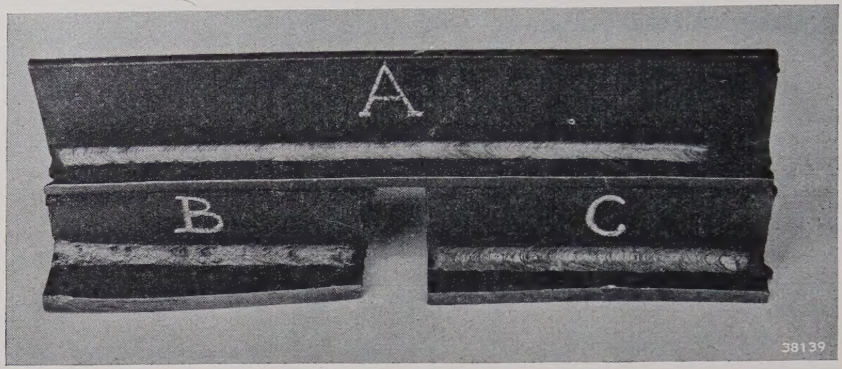

Fig. 11. Fillet weld in free-cutting steel (0.23 per cent sulphur, 0.08 per cent phosphorus). The right-hand half is welded with an ordinary good quality welding rod (quite porous weld), the left-hand half with the Philips rod 55 (tight weld).

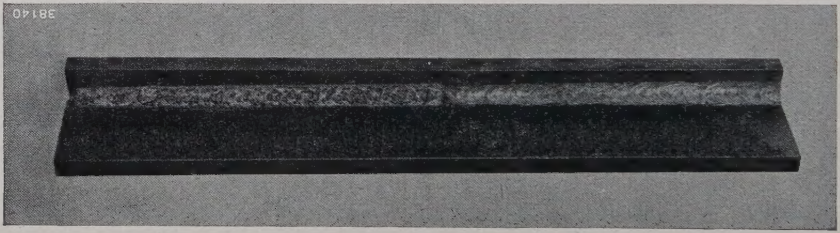

Fig. 10. *A* fillet weld made with an ordinary good quality welding rod on St 37 with normal sulphur content (0.03 per cent). *B* fillet weld with the same rod on steel rich in sulphur (0.09 per cent); holes may clearly be seen in the weld which has a "burned" appearance (so-called pock-marked). *C* fillet weld on the same steel rich in sulphur made with the Philips rod 55; the weld is quite sound.

INCANDESCENT FILAMENT LAMPS FOR SERIES-CONNECTION

by N. A. HALBERTSMA and J. A. M. van LIEMPT. 621.316.062.2 : 621.326

Although it is at present customary to connect electrical apparatus in multiple to the supply main, series connection of lamps may offer advantages, under certain circumstances. In order to avoid extinction of the whole installation when one lamp becomes defective special measures are taken which are described in this article.

Introduction

The advantages of multiple connection of the lamps in a system of illumination over the series connection which was formerly often used, consist chiefly in the fact that the lamps are independent of each other. This is usually considered to be of such great importance that in designing illumination systems no other possibility is as a rule considered. By way of exception, however, connection in series is also sometimes used, in spite of the fact that the possibility of switching on any desired number of lamps and the free choice of the size of the lamps must be sacrificed.

The use of series-connection is justified when:

1) the available voltage is too high for the lamps to be used, and
2) the simplification obtained is important.

All cases in which connection in series is used, as the lighting of trams and trains, illumination and Christmas tree lighting and, to a limited extent, street and highway lighting, can always be classified in one of these two groups.

The available voltage is too high for the lamps to be used.

In the case of A.C. installations the voltage can be lowered to any desired value in a simple manner with the help of a transformer. In the case of D.C. installations, however, the voltage is fixed. It is for this reason that the connection of electric lamps in series is usually used for the lighting of trams and trains. The D.C. voltage on the trolley wire is usually 500 to 600 volts; the highest voltage for which electric lamps are made is 260 volts. As a rule with a voltage of 600 volts 5 lamps of 120 volts are connected in series; sometimes a larger number of lamps of a lower voltage are preferred. If the traction voltage is 1 500 volts and higher it is advisable not to introduce this voltage in parts of the coaches, where is would be accessible to the public. It is better to use a converter to supply current to a distribution system for lighting and other purposes, and then ordinary multiple connection can be used.

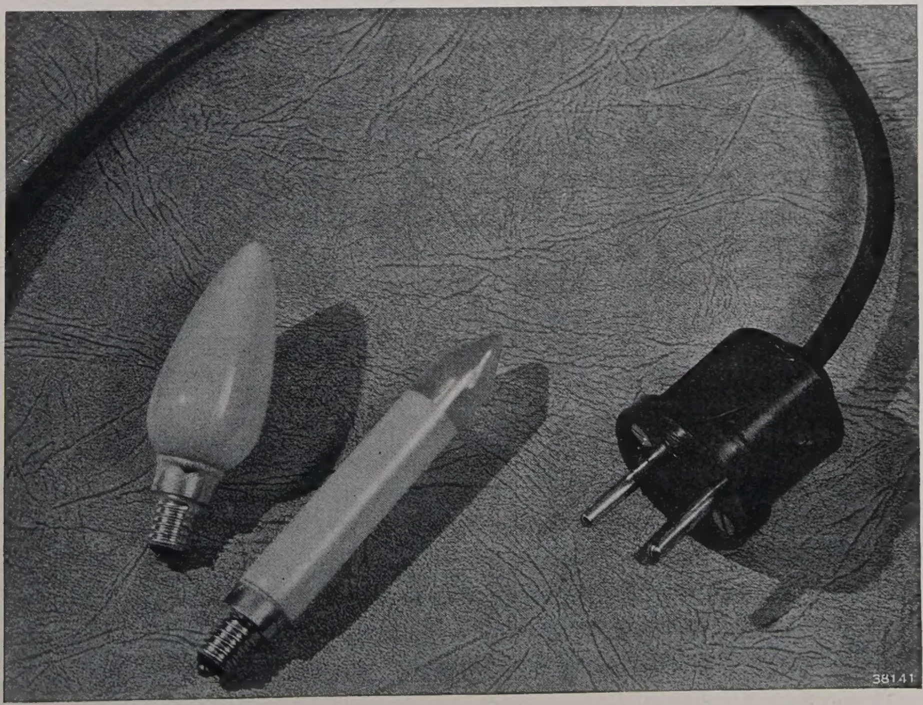

Fig. 1. Illumination and Christmas tree lamps, both for 14 volts, 3 c.p.

The ordinary mains voltages of 230 volts and 115 volts may also in certain cases be too high for the lamps which must be used. The smallest ordinary electric lamp for 230 volts and 115 volts has a light flux of 15 dlm, and a consumption of about 15 watts. Lamps with smaller wattage, such as those for illuminations and Christmas trees, must be made for a lower voltage because of the limit imposed by the thickness of the wire. A voltage of 14 volts with a light intensity of 3 c.p. is the most common. With a consumption of 3.75 watts these lamps have a current of 0.27 A. The filament is short and stout, the lamp which is small (*fig. 1*) may be provided with a small-sized screw cap. The lamp holder is thus also small, which is important since the lamps are used for decoration. On 220 volt mains 16 such lamps can be connected in series, and on mains of lower voltage a correspondingly smaller number.

The simplification of the installation

In connection in series there is only one conductor which passes from socket to socket, while in multiple connection two wires must branch off to every lamp socket. This makes the installation so much simpler that in certain cases series-connection will be preferred. The illumination of a Christmas tree is effected more rapidly with a single thin flex than with the thicker double flex which must be used for multiple connection.

The simplification of the installation is also important in the installation of street lighting systems with series-lamps as is often found in the United States. For new installations, however, in the United States preference is usually given to connection in parallel. In Europe the connection in series for street lighting has only been used on a large scale in Italy.

When a very long traject must be illuminated with light sources of small power and considerable spacing, the connection in series may offer advantages with respect to the cost of installation. Along both sides of the Amsterdam - IJmuiden Canal for 15 miles there is a series installation with lamps of 65 watts spaced at 900 ft.

Disadvantages of series-connection in practice

In addition to the objection already mentioned that with connection series it is impossible to change at will the number of lamps burning, there is the further disadvantage that if one of the lamps becomes defective the whole series is extinguished. In a tramcar, for example, this would be very inconvenient, since one is then compelled to hunt for the burnt out lamp in the dark in order to replace it. The lamp which has failed is, however, indistinguishable from the others, and the hunt for the defective lamp has long been an unpleasant aspect of the use of series-connection of electric lamps.

For this reason devices have been applied, particularly for street lighting, for the automatic short-circuiting of a defective lamp. Two aims are hereby achieved, namely

1) that all the lamps of the series except the defective one continue to burn, and
2) that the defective lamp can easily be found since it is the only one extinguished.

In order to maintain the amperage entirely unchanged, the burnt-out lamp should actually be replaced by an equivalent resistance. If, however, the lamp is short-circuited, the resistance of the whole series will decrease and the current will increase slightly. The smaller the number of lamps in series, however, the greater the overloading of the remaining lamps. In tramway cars where for instance 5 lamps of 120 volts burn in series, the voltage per lamp would rise by 25 per cent, *i.e.* to 150 volts. It is therefore necessary to take measures to bring the current quickly back to its normal value in order to avoid the failure of more lamps due to the excess voltage. If such measures are impossible, it is advisable to use lamps with a lower voltage. Voltages of 24, 30, 40 and 50 volts may be used.

Automatic short-circuiting arrangements for burnt out series lamps

For the automatic short-circuiting of a lamp in a series very different devices have been proposed. Use has for instance been made of the interruption of the current to short-circuit the lamp by means of a relay, or to replace it by an equivalent resistance. The interruption of the light may in this case be of such a short duration that scarcely more than a flicker is observed.

The rise in voltage at the terminals of the defective lamp may also be used to bring about short circuiting, due to the fact that a very thin layer of insulation material held between two metal contacts breaks down. In the United States such devices are used as a rule in series street lighting systems. The flash-over device consists of two aluminium discs one of which is provided with a thin insulating layer which breaks down at about 400 volts. The disc is clamped between two contact springs fastened to the lampholder, which contact springs serve at the same time to make the connection between the lampholder and the terminals.

When a lamp burns out the lamp with the holder can be removed from the fitting and the lamp and flash-over device both renewed without any risk of touching parts under tension.

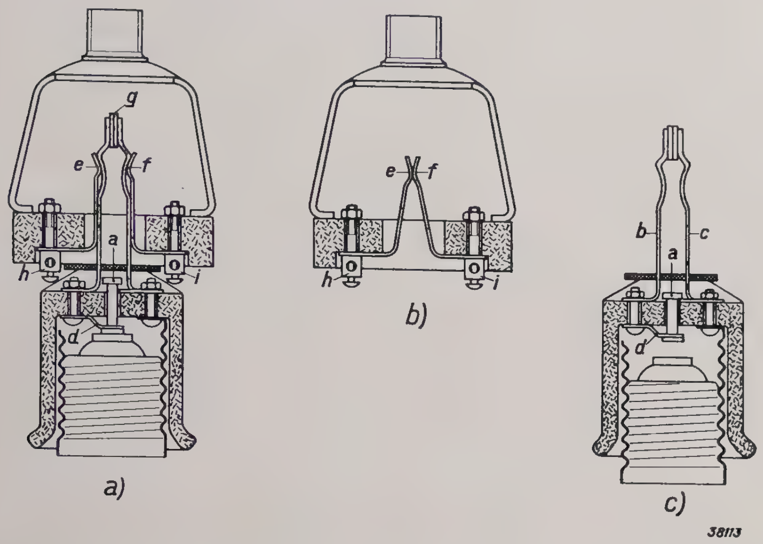

Fig. 2. Lamp-holder with short-circuiting device for street lighting with series-lamps, *a*) ready for use, *b*) lamp-holder with lamp and voltage fuse removed and *c*) lamp-holder with voltage fuse and lamp. *a* contact, *b* and *c* disc holder, *d* flexible strip, *e* and *f* contact springs, *g* flash-over disc, *h* and *i* terminals.

Screwing out a lamp which forms part of a series installation is dangerous, not only because of the risk of touching a part under tension, but also for another reason. If the current continues to flow, especially in the case of direct current, an arc will occur between the centre contact of the holder and the centre contact of the screw cap, which will melt the metal parts mentioned. The lamp holder shown in *fig. 2* has another short-circuit contact for preventing this, which is connected to the flexible middle contact and comes into action as soon as the lamp has been screwed out of the lampholder a fraction of an inch, and before contact with the centre contact of the cap is broken.

In analogy with the fuses which come into action when a definite current value is exceeded, the flash-over devices may be called "voltage fuses", since they come into action as soon as a definite voltage is reached, which is higher than the rated voltage of the lamp but lower than the mains voltage.

The voltage fuses, which may be incorporated in the lamp itself or connected separately to the lamp-holder, must satisfy very divergent requirements. At the burning voltage of a single series-lamp they must have an infinite resistance, but at the total voltage applied to the series they must break down and restore the circuit. In street lighting with series-lamps this is not difficult to achieve, due to the high voltages occurring. There are numerous insulating materials which will break down when exposed in a very thin layer to voltages of 3000-10 000 volts, while at several hundred volts they exhibit practically no conductivity.

In tramcar lighting the breakdown voltage must lie below 400 to 500 volts and above the rated voltage of the lamp, and when, to mention another example, a series of lamps for illumination of 7 or 14 volts is connected to a main of 115 volts, the voltage fuse must operate between 20 and 100 volts. Very thin insulating layers are necessary for this, and they should have little spread in the breakdown voltage. It is indeed possible to produce such fuses.

For the operating of the voltage fuses it is a matter of some importance whether the lamps in series are vacuum lamps or gas-filled lamps. When the filament fails of a vacuum lamp which is not provided with a voltage fuse no electric discharge can take place, due to the absence of gas molecules in sufficient quantities, the vacuum acting

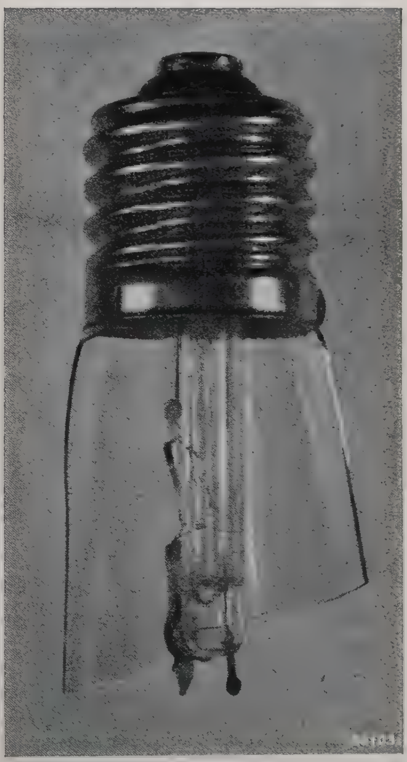

Fig. 3. Photograph of a series lamp which has been destroyed by an arc discharge.

as an insulator and the current is simply interrupted. The case is different with a series gas-filled lamp without a voltage fuse. In this case, when the filament of the burning lamp fails, the current need not immediately be interrupted. An arc may occur at the break of the spiral which heats the ends to such a high temperature that they begin to melt. The other lamps of the series now serve as a resistance, stabilizing this arc discharge. It sometimes occurs that the spiral is entirely fused away and that the arc strikes over to the leading-in wires of the lamp. The latter then also fuse, so that, unless the lamp has already been destroyed by the heat developed, the arc finally arrives in the neighbourhood of the foot (*fig. 3*) and not only destroys the glass with the leading-in wires, but may also pass over to the lamp cap and even to the metal parts of the lamp holder. Such an arc may, especially with direct current and under conditions favourable to its maintenance, cause considerable damage.

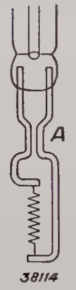

Fig. 4. In order to promote the rapid occurrence of short circuiting by the arc the leads of this series lamp are brought close together at *A*.

This process can, as stated, only take place in the absence of a voltage fuse or when the latter does not work, of which there is a certain chance since the voltage of the arc may remain below the breakdown-voltage of the voltage fuse. The solution of this difficulty might be sought in raising the voltage of the arc when it occurs by placing the leading-in wires as far apart as possible. This would, however, result in difficulties in connection with the introduction of the filament system through the narrow neck of the bulb; the solution has therefore been sought in just the opposite direction, namely by bringing the wires very close together. If an arc is produced the leads will fuse off until at *A* in *fig. 4* the drops of molten metal on the ends of the nickel wires short-circuit the lamp and thus prevent both a break of the circuit and damage to the lampholder.

If the lamp has very short leading-in wires which are difficult to bend close to each other, they are provided with separate wires which serve as "arc catcher" (*fig. 5*). Even when these measures have been taken a voltage fuse is not superfluous. If for example a spiral breaks (by shock, for instance) while the lamp is not burning, no arc will occur when the series of lamps is switched on. In this case the voltage fuse must break down and short-circuit the defective lamp before the series of lamps actually lights.

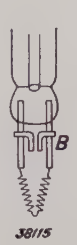

Fig. 5. Series-lamp with separate arc-catcher *B*.

The type of voltage fuse varies according to the voltage at which it must act. The piece of thin paper formerly employed has been universally replaced by an insulating material which is deposited on metal. Metal oxides which are good insulators are preferred. In the oxidation process it is possible to control the thickness of the oxide film. A film of aluminium oxide is usually used which with the dimensions used for a breakdown voltage of about 400 volts has a resistance of 10^8 ohms, and may thus be considered as an insulator. After breakdown this resistance falls practically to zero. For illumination and Christmas tree lamps the breakdown voltage must be so low (below 100 volts) that aluminium oxide cannot be used. The film would have to be so thin that it is not to be realized in practice. Therefore a sodium tungstate is used in these cases, the so-called blue tungsten bronze, which still has a low breakdown voltage at a greater thickness of the layer.

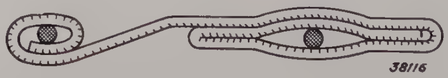

Fig. 6. Metal-strip covered with aluminium oxide which is bent around the leading-in wires in such a way that only one layer needs to break down to cause a conducting connection between the wires.

In the case of vacuum lamps the voltage fuse is mounted between the screw cap and the glass of the bulb. It cannot be placed in the bulb itself because the oxide films used contain gases which would spoil the vacuum of the lamp. In gas-filled lamps the gas freed from the oxide is of no importance. The strip with aluminium oxide can be bent around the lead-in wires (*fig. 6*), if desired combined with a nickel strip which serves as arc catcher (*fig. 7*). This voltage fuse shown in fig. 7, may be seen in *fig. 8* mounted inside the bulb of a gas-filled series lamp for tramcar lighting. The voltage fuse of fig. 6 may be seen in *fig. 9* mounted in the screw cap of a vacuum series lamp which is shown in its true dimensions.

In the case of illumination and Christmas tree lamps the voltage fuse, in spite of the small space available, can be placed in the tiny screw cap due to its simple construction. An example is shown in *fig. 10*.

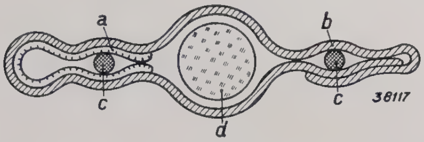

Fig. 7. Combination of an aluminium strip (*a*), provided with an insulating layer of aluminium oxide with a nickel strip (*b*), which serves as arc catcher. *c* leading-in wires, *d* glass rod.

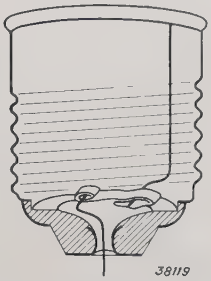

Fig. 9. In vacuum series-lamps the voltage fuse shown in fig. 6 is mounted into the screw-cap. The sketch is full size and shows the small dimensions of the voltage fuse.

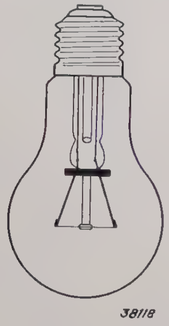

Fig. 8. Series-lamp (gas-filled) for tramcar lighting for 40 volts, 40 watts (1 amp.), in which the voltage fuse shown in fig. 7 has been mounted.

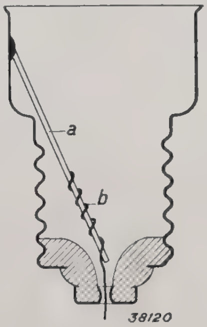

Fig. 10. Miniature screw-cap for small illumination lamps, twice natural size, in which an extremely simple voltage fuse has been mounted. *a* tungsten wire covered with tungsten bronze, around which a metal wire *b* is wound.

NON-LINEAR DISTORTION OF SOUND FILM WITH OBLIQUE LIGHT SLIT

by J. F. SCHOUTEN. 778.534.45 : 621.396.813

When a sound film is recorded or scanned with a light slit which is not exactly perpendicular to the direction of length of the film, a non-linear distortion of the sound occurs. An exact calculation of this distortion was considered impossible until now. In this article it is shown that the calculation is indeed possible, and even relatively simple, when the light diffraction at the sound film is used for assistance. The diffraction spectrum consists of a two-dimensional pattern whose light distribution along a given axis (parallel to the direction of the film) provides the Fourier spectrum of the sound obtained upon reproduction. With an "obliquely recorded" film the diffraction pattern is also found to be obliquely distorted, and with this very simple transformation the new Fourier spectrum can immediately be derived, when the diffraction pattern of the "vertically recorded" film is completely known. In this way the distortion with oblique slit is calculated and discussed for the cases where one is concerned with only one frequency, and where one is concerned with two different frequencies in the sound track.

The problem of the oblique slit in sound film technology

If upon reproducing sound film the narrow light slit with which the film is scanned is not perpendicular to the direction of length of the film (*fig. 1a*), then when the sound track on the film is sinusoidal the amount of light transmitted does not vary truely sinusoidally with the time (fig. 1*c*). A non-linear distortion occurs which is manifested acoustically in that the sound contains higher harmonics in addition to the fundamental tone.

A similar phenomenon will occur when in recording the film the light slit (in the photographic system) or the cutter (in the Philips-Miller system, where the sound track is cut in the film [1])) is not perpendicular to the direction of length of the film. A sound track results which as it were slants (fig. 1*b*), and which upon reproduction with a straight slit leads in the same way to non-linear distortion.

The fact that upon oblique scanning non-linear distortion must occur was already pointed out in 1881 by König [2]) in the discussion of his "wave syren", a forerunner of the sound film. The problem only became actual in sound film technology. Frieser and Pistor [3]) found in their attempts at an exact calculation that even with a single frequency they encountered unsolvable equations, and they confined themselves to working out several cases graphically. Podliasky [2]) gave an approximate calculation, also for the case of a single frequency, for the relative intensity of the second harmonic which occurs at very small angles of the slit. The problem of the general calculation of the distortion was, however, considered insoluble until now.

We shall show how with the help of the previously described light diffraction by sound film [3]) an exact and, moreover, very clear solution of this problem can be obtained in a relatively simple way.

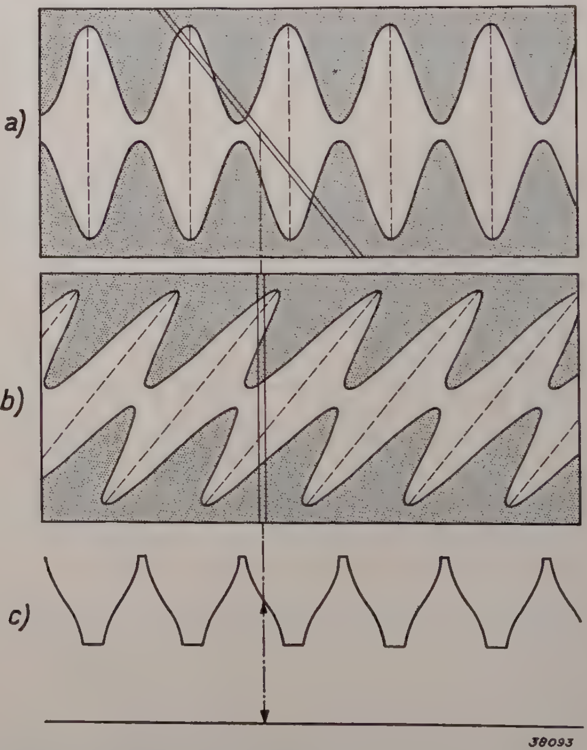

Fig. 1. If a piece of film is scanned with a light slit which is oblique with respect to the direction of length of the film (*a*) or if the sound track is recorded with an oblique slit (*b*), in both cases non-linear distortion of the sound results: the amount of light transmitted with a sinusoidal sound track is no longer sinusoidal but as shown in (*c*).

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[1]) R. Vermeulen, Philips techn. Rev. **1**, 107, 1936. The strips of film reproduced in this article were all recorded by this system. For the sake of simplicity, however, we shall always speak of a light slit.

[2]) R. König, Wied. Ann. Phys. **12**, 335, 1881.
H. Frieser and W. Pistor, Z. techn. Phys. **12**, 116, 1931.
I. Podliasky, Annales P.T.T. **24**, 1, 1935.

[3]) J. F. Schouten, Philips techn. Rev. **3**, 298, 1938; **4**, 290, 1939.

Before passing on to the actual calculation we shall indicate the relation between light diffraction by sound film and non-linear distortion in a general way.

General consideration of the diffraction pattern of obliquely recorded sound film

We have previously described [3]) how a strip of sound film can be used to produce optical interference phenomena. A diffraction pattern is obtained which is also important acoustically. The very general proposition can be deduced *that the light distribution on a given line in this diffraction pattern* (namely the horizontal axis through the middle of the pattern, indicated below) *gives the exact Fourier analysis of the sound recorded on the film* [4]).

In *fig. 2* a strip of film is shown on which a tone of 400 c/s has been recorded, with the diffraction pattern obtained from it. Along the horizontal axis only three lines are encountered, a central line (zero order) and lines to the left and right of it (first order), which means that the strip of film contains only the frequencies zero — the average width of the film track may be considered as such — and 400.

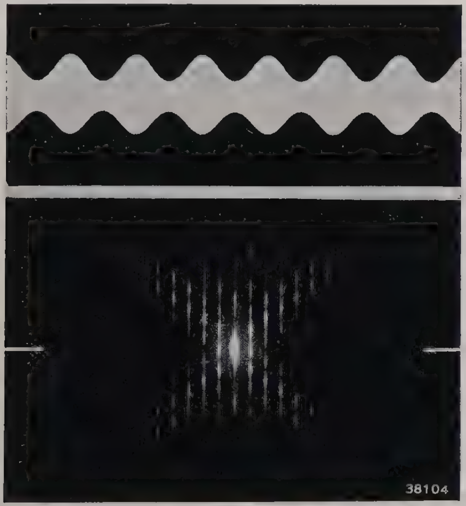

Fig. 2. Light diffraction by sound film. Above: sound track (tenfold enlargement) of a tone of 400 c/s recorded with vertical slit. Below: the diffraction pattern obtained. On the horizontal axis only the lines of the zero and first orders are visible.

The pattern outside the axis here has no acoustic significance. While the pattern actually also contains lines of higher orders (*i.e.* at greater distances from the centre), since these lines do not occur on the horizontal axis, the sound recorded on the film does not contain the corresponding frequencies of 800, 1 200, etc.

Let us now consider the diffraction pattern of a strip of film upon which the same frequency is recorded obliquely (*fig. 3*), with a (very exaggerated) angle of 15 degrees. The pattern again contains the same lines of higher order, each line with the old intensity distribution in the vertical direction [5]), but shifted in that direction over a distance proportional to the number of the order.

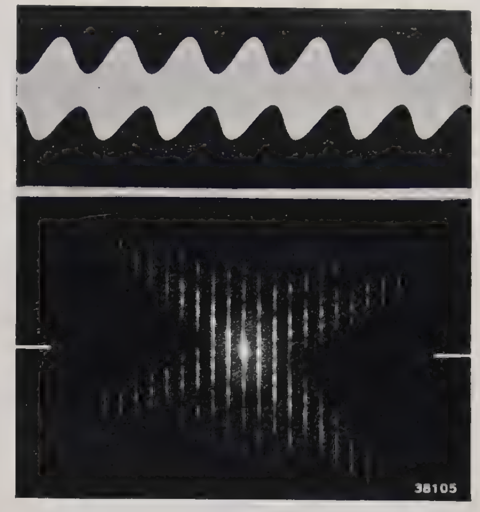

Fig. 3. The same as fig. 2, but for recording with an oblique slit. The diffraction pattern is identical with that of fig. 2 except for a displacement of the lines in a vertical direction.

This results in the fact that the second, third and fourth orders are shifted on the horizontal axis with appreciable intensity, and therefore upon reproduction will occur in the sound as second, third and fourth harmonics.

The optical spectrum of a vertically recorded sound track thus gives us complete insight into the sound spectrum which will be obtained upon oblique recording or reproduction. *The higher orders are as it were ready to slide across the horizontal axis upon oblique recording and to become observable in the sound as higher harmonics.*

In principle quite the same behaviour is found with more complicated vibration forms (figs. 17 and 18). Here also the general structure of the pattern remains intact, the lines, however, are shifted along each other and may thereby cause an appreciable intensity on the horizontal axis.

The calculation of the non-linear distortion caused by an oblique position of the light slit thus falls into two steps: the calculation of the normal diffraction pattern and the calculation of the shifts which this pattern undergoes due to the oblique position of the light slit [6]).

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[4]) J. F. Schouten, Physica 7, 101, 1940.

[5]) Except for a slight difference which may be ascribed to the slightly wider zero track and the slightly greater amplitude of the sound on this film.

Calculation of diffraction pattern

The diffraction pattern of the perforated grating

Consider a parallel beam of light which is incident perpendicularly on the surface of the film. If there is a small hole in the film the light is diffracted uniformly in all directions by this hole when we confine ourselves to small angles of diffraction.

The coordinates of the rectangular hole are u and v, its width and height du and dv, respectively, and the angles of diffraction in horizontal and vertical direction α and β, respectively. We consider first the diffraction of the rays in the horizontal direction and draw the projection on the horizontal plane through the u axis, see *fig. 4*. In this drawing a ray through the point u is given which is diffracted through a horizontal angle α and a similar ray which would pass through the point zero.

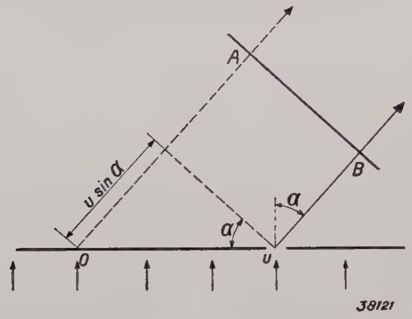

Fig. 4. Light diffraction at a hole (projection in the horizontal plane).

On an arbitrary line AB perpendicular to the path of the rays (the wave front) there is a difference in path covered $u \sin \alpha$ between the two rays, and thus a phase difference $(2\pi u \sin \alpha)/\lambda$, when λ represents the wave length of the light used. If we represent the light vibration at A by $\sin \omega t$ (ω is the angular frequency of the light used), the light vibration at B varies according to $\sin (\omega t + 2\pi \alpha u/\lambda)$, where $\sin \alpha$ has been replaced by α since we have limited the case to very small angles of diffraction. When we pass on to the two-dimensional case, where the influence of the vertical component v and the vertical angle of diffraction β are taken into account, it is found that the ray α, β from the hole u, v with the dimensions du and dv may be represented in a corresponding way by

$$\sin\left(\omega t + \frac{2\pi\alpha}{\lambda} u + \frac{2\pi\beta}{\lambda} v\right) \mathrm{d}u \, \mathrm{d}v \quad . \quad . \quad (1)$$

When a positive lens is placed behind the film (*fig. 5*) every point in the focus corresponds to a direction α, β of diffraction. The coordinates of this focus are therefore equal to α and β, respectively, except for a factor. According to (1) the focal plane is homogeneously illuminated, since the amplitude of the light oscillation is independent of α and β; the phase, however, contains α and β, and therefore differs from point to point.

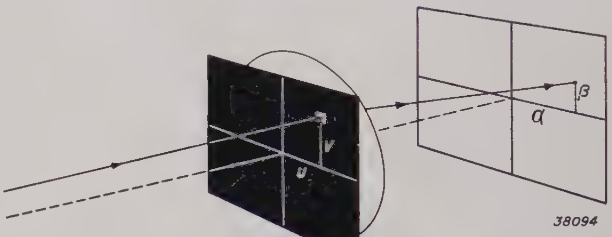

Fig. 5. Schematic representation of the arrangement for diffraction experiments. The strip of film is illuminated with a parallel beam of light. A lens is placed behind the film which concentrates all the rays diffracted by the same angles α, β in one point of the focal plane. There is assumed to be a rectangular hole in the film with the coordinates u, v.

Let us now imagine on the film an infinitely long horizontal row of holes at equal intervals l with the coordinates $u = x$, $x + l$, $x \pm 2l$, etc., see *fig. 6a*. On the focal plane the contribution of the m^{th} hole to the light oscillation is

$$\sin\left\{\omega t + \frac{2\pi\alpha}{\lambda}(x + ml) + \frac{2\pi\beta}{\lambda} v\right\} \mathrm{d}x \, \mathrm{d}v \quad . \quad . \quad (2)$$

The total oscillation is then obtained by summation over all the holes. Physically this means an inter-

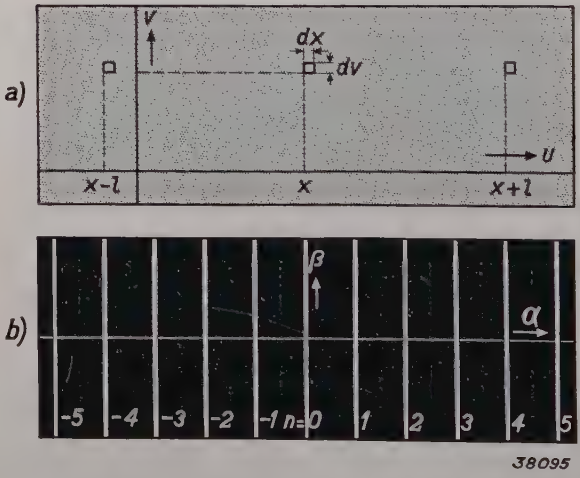

Fig. 6. A perforated grating (*a*), consisting of an infinite row of holes at height v and at distances l apart, causes a diffraction pattern which contains an infinite number of equidistant vertical lines (*b*) along which the light has a constant amplitude.

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[6] Mathematically speaking, the calculation of the non-linear distortion has of course nothing to do with the light diffraction. The method should only be considered as a welcome aid in bringing the very abstract manner of calculation (namely with the help of two-dimensional Fourier analysis) into expression in a graphic manner.

ference between rays having the same direction and coming from different holes. For certain directions, namely for values of a for which

$$a_n = \frac{n\lambda}{l}\,, \text{ mit } n = 0, \pm 1, \pm 2, \ldots, \quad (3)$$

the phase difference between each pair of rays will be an integral multiple of 2π, independent of m, whereby all the rays reinforce each other; for all intermediate directions the rays will cancel each other. The focal plane is therefore no longer homogeneously illuminated, the only light which remains is at a series of infinitesimally narrow vertical lines (fig. 6*b*).

For the amplitude of the light oscillation at these lines we would find infinity upon summation over the infinite number of holes. In the following, however, we shall consider the contribution per unit length of the film [7]). At the n^{th} line the contribution of each hole is equal to

$$\sin\left\{\omega t + \frac{2\pi a_n}{\lambda} x + \frac{2\pi\beta}{\lambda} v\right\} \mathrm{d}x\, \mathrm{d}v,$$

per unit length of the film therefore

$$L_n = \frac{1}{l} \sin\left\{\omega t + \frac{2\pi a_n}{\lambda} x + \frac{2\pi\beta}{\lambda} v\right\} \mathrm{d}x\, \mathrm{d}v\,. \quad (4a)$$

or, when (3) is substituted and when for the sake of simplicity we set $2\pi\beta/\lambda = b$,

$$L_n = \frac{1}{l} \sin\left\{\omega t + \frac{2\pi n}{l} x + bv\right\} \mathrm{d}x\, \mathrm{d}v\,. \quad (4b)$$

If, as will be the case in the following, we confine ourselves to the calculation of periodic gratings, we may always consider them to be made up of the sum of a large number of perforated gratings of the same period, shifted with respect to each other in horizontal and vertical direction. Each of these perforated gratings, independent of its position x, y, leads to the same set of equidistant lines (3), with, however, a difference in phase. The resulting periodic grating, no matter what complex form it may have in every period, will therefore only be able to exhibit intensities on the same vertical lines, and will only be distinguished by different intensity distributions in a vertical direction.

As a following step we shall now derive the diffraction pattern of the slit grating.

The diffraction pattern of the slit grating

A grating consisting of equidistant vertical slits which extend from $v = 0$ to $v = y$ (*fig. 7a*) may be considered as the sum of perforated gratings placed vertically one above the other. The diffraction pattern obtained is the sum of the patterns of the individual perforated gratings. It is obtained by the integration of (4b) with respect to dv:

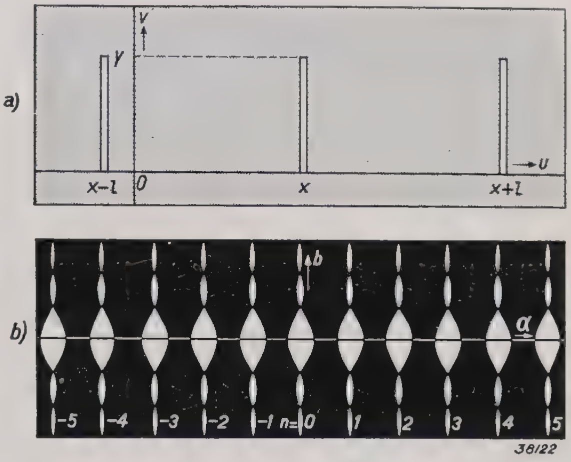

Fig. 7. A slit grating (*a*) with a height *y* and the period *l* causes a diffraction pattern (*b*) which consists of vertical lines in the same positions as in fig. 6*b*. Along each line, however, the amplitude of the light now varies periodically. This is indicated in the drawing by a variation of the thickness of the line.

$$L_n = \frac{1}{l}\,\mathrm{d}x \int_0^y \sin\left(\omega t + \frac{2\pi n}{l} x + bv\right) \mathrm{d}v$$

$$= \frac{1}{bl}\left\{\cos\left(\omega t + \frac{2\pi n}{l} x\right) - \cos\left(\omega t + \frac{2\pi n}{l} x + by\right)\right\} \mathrm{d}x \quad . \ (5a)$$

$$= \frac{2}{bl} \sin\frac{by}{2} \cdot \sin\left(\omega t + \frac{2\pi n}{l} x + \frac{by}{2}\right) \mathrm{d}x \quad \ldots\ldots\ldots \ (5b)$$

For each line n the amplitude of the light oscillation as a function of the vertical coordinate b is therefore given by the same function

$$\frac{2}{bl} \cdot \sin\frac{by}{2}\,\mathrm{d}x.$$

The amplitude [8]), which in the case of the perforated grating was constant over a whole line, has now become periodic along each line and the intensity of the maxima decreases proportionally to b (fig. 7*b*).

The diffraction pattern of a sinusoidal track. Unilateral modulation

If we now join slit gratings of different height y (but with the same period l) together in a horizontal direction, we obtain what is called in sound film technology a modulated sound track. For a pure tone

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[7]) In practice one is always concerned with a finite length of film. This is manifested (loc. cit.[3,4]) solely in a slight broadening of all the lines in the diffraction pattern, but leaves the macro structure of the pattern unaltered.

[8]) In visual or photographic observation of the spectrum one will always be concerned with the intensity of the light, which is proportional to the square of the amplitude of the light. For our considerations, however, it suffices if we deal with the amplitude in all cases.

$$y = p + q \cos \frac{2\pi x}{l}, \quad \cdot \cdot \cdot \cdot \cdot \quad (6)$$

where p represents the width of the "zero track", and q the amplitude of the signal (*fig. 8*); 100 q/p is the percentage depth of modulation. In this way a so-called unilateral modulation has been obtained which indicates that only one boundary of the zero track is varied.

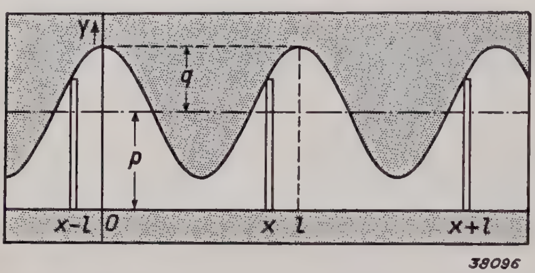

Fig. 8. A sound track containing a unilaterally modulated sine may be built up of a series of slit gratings, all of which have the same period l, but which are shifted with respect to each other in the horizontal direction. The zero track has the width p, the amplitude of the sine curve is q.

If we substitute condition (6) in (5a), and integrate with respect to dx, we obtain

$$L_n = \frac{1}{bl} \int_0^l \cos\left(\omega t + \frac{2\pi n}{l} x\right) \mathrm{d}x -$$

$$- \frac{1}{bl} \int_0^l \cos \left\{\omega t + \frac{2\pi n}{l} x + b\left(p + q \cos \frac{2\pi x}{l}\right)\right\} \mathrm{d}x.$$

The second integral upon working out contains terms of the form

$$\cos\,(bq \cos 2\pi x/l) \text{ and } \sin\,(bq \cos 2\pi x/l),$$

which cannot immediately be reduced to goniometric functions, but which may be expressed in a series with Bessel functions:

$$\cos\,(\xi \cos \Theta) = \sum_{k=-\infty}^{k=+\infty} (-1)^k \cos 2k\Theta \cdot J_{2k}\,(\xi),$$

$$\sin\,(\xi \cos \Theta) = \sum_{k=-\infty}^{k=+\infty} (-1)^k \cos\,(2k+1)\Theta \cdot J_{2k+1}\,(\xi).$$

By this means the expression for the light oscillation in the diffraction spectrum may be reduced to

$$L_n = -\frac{1}{b} \cos\left(\omega t + bp + \frac{n\pi}{2}\right) J_n\,(bq) \quad . \quad (7a)$$

for $n = \pm 1, \pm 2, \pm 3, \ldots$, while the zero order is given by

$$L_0 = \frac{1}{b} \cos \omega t - \frac{1}{b} \cos\,(\omega t + bp)\, J_0\,(bq) \,.\;. \quad (8a)$$

In these formulae J_n represents the Bessel function of the n^{th} order.

For a good understanding of the character of the diffraction spectra we shall for a moment consider the behaviour of these functions. They may be developed as follows in exponential series:

$$J_0(\xi) = 1 - \frac{\xi^2}{2^2} + \frac{\xi^4}{2^2 \cdot 4^2} - \frac{\xi^6}{2^2 \cdot 4^2 \cdot 6^2} + \ldots = +J_0\,(-\xi),$$

$$J_1(\xi) = \frac{\xi}{2} - \frac{\xi^3}{2^2 \cdot 4} + \frac{\xi^5}{2^2 \cdot 4^2 \cdot 6} - \ldots = -J_1\,(-\xi) = -J_{-1}\,(\xi),$$

$$J_2(\xi) = \frac{\xi^2}{2 \cdot 4} - \frac{\xi^4}{2^2 \cdot 4 \cdot 6} + \frac{\xi^6}{2^2 \cdot 4^2 \cdot 6 \cdot 8} - \ldots = +J_2\,(-\xi) = +J_{-2}\,(\xi),$$

$$J_3(\xi) = \frac{\xi^3}{2 \cdot 4 \cdot 6} - \frac{\xi^5}{2^2 \cdot 4 \cdot 6 \cdot 8} + \ldots = -J_3\,(-\xi) = -J_{-3}\,(\xi),$$

$$J_4(\xi) = \frac{\xi^4}{2 \cdot 4 \cdot 6 \cdot 8} - \frac{\xi^6}{2^2 \cdot 4 \cdot 6 \cdot 8 \cdot 10} + \ldots = +J_4\,(-\xi) = +J_{-4}\,(\xi),$$

usw.

As shown by the series and *fig. 9*, $J_0(\xi)$ shows great similarity to a cosine, although with gradually decreasing amplitude. $J_1(\xi)$ has the character of a sine, while the Bessel functions of higher orders are also oscillating functions but with progressing retardation as concerns their commencement. They reach their first maximum at a value of the argument which is greater than the order n by about one.

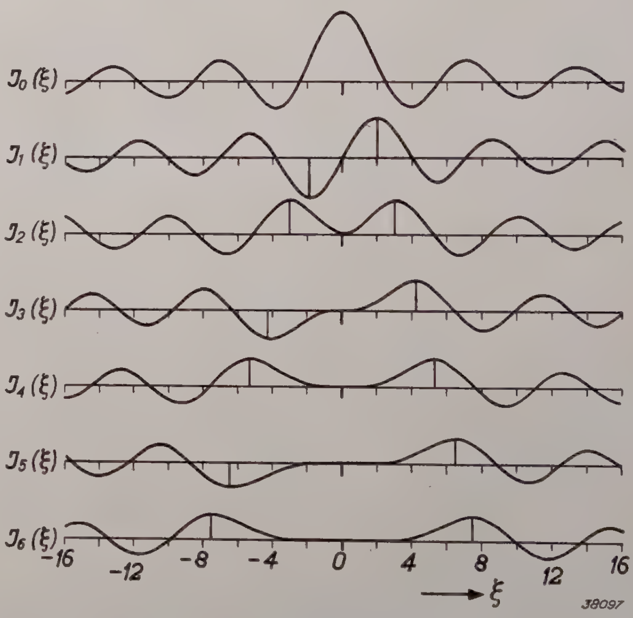

Fig. 9. Graphical representation of the Bessel functions ($J_n(\xi)$ for the orders $n = 0$ to $n = 6$.

According to (7a) and (8a) the intensity distribution along the line of n^{th} order in the diffraction pattern is determined by the Bessel function of that order. More exactly: the amplitude of the light is given by the quantity

$$\left| \frac{J_n\,(\xi)}{\xi} \right|$$

This quantity is represented graphically in the model of *fig. 10* by a number of positive and negative integral orders (except $n = 0$). The behaviour of the functions corresponds in character to that of the Bessel functions themselves (fig. 9), and this behaviour is found to be perfectly reflected in the spectrum recorded, *fig. 11*. It may be seen that the higher orders reach their first maximum at steadily increasing values of b, which gives the whole pattern the form of a St Andrew's cross.

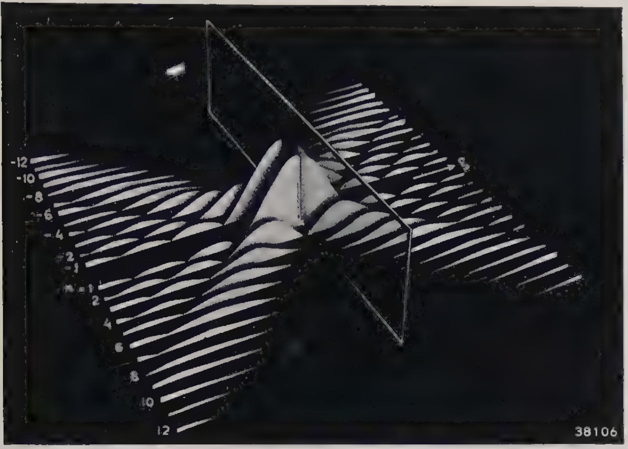

Fig. 10. Model of the function $J_n(\xi)$ for a number of whole number orders n, except zero. The vertical celluloid screen represents the plane through the axis $\xi = 0$. In this plane the function differs from zero only for $n = \pm 1$.

For the amplitude on the horizontal axis ($b = 0$) it follows from (7a) and (8a) that:

$$A_0 = p$$
$$A_1 = q/2$$
$$A_2 = A_3 = A_4 = \ldots = 0.$$

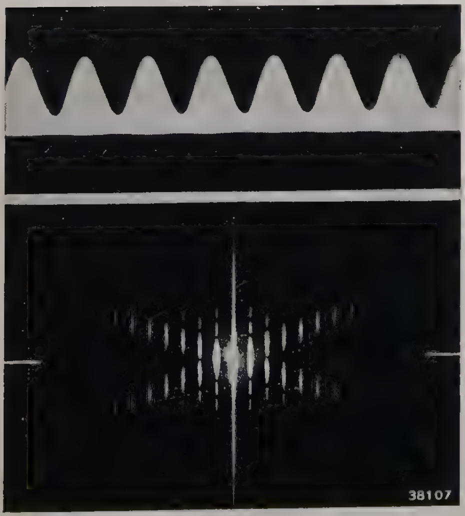

Fig. 11. Photograph of the diffraction pattern of the unilaterally modulated sine (ν = 400 c/s). The light distribution in this pattern is given by the model shown in fig. 10. The horizontal axis $b = 0$ corresponds to the celluloid plane $\xi = 0$.

This confirms the proposition made at the beginning in the general considerations that the diffraction pattern on the horizontal axis provides the Fourier analysis of the sound: the zero order is determined exclusively by the width q of the zero track, the first order exclusively by the amplitude q of the signal, while all the higher orders have a zero intensity.

The diffraction pattern of a sinusoidal track. Bilateral modulation

At the present time it is almost universally customary in sound film technology to vary not one, but both boundaries of the zero track simultaneously. We shall derive the diffraction pattern so obtained from that of the unilaterally modulated track, and for this purpose we shall consider the bilaterally modulated track to consist of two parts: the part above and the part below the x-axis, *i.e.* two unilaterally modulated tracks. The upper part furnishes the pattern which we have already derived, the lower part is obtained by not integrating from 0 to y in the calculation of (5), but from $-y$ to 0. This comes down to substituting in formulae (7a) and (8b) $-p$ and $-q$ for p and q, and giving the whole a negative sign. This gives:

$$L_n' = +\frac{1}{b}\cos\left(\omega t - bp + \frac{n\pi}{2}\right) J_n(-bq), \;.\;. \quad (7b)$$

$$L_0' = -\frac{1}{b}\cos\omega t + \frac{1}{b}\cos(\omega t - bp)\, J_0(-bq)\,. \quad (8b)$$

If the two patterns are now added together we obtain for all orders the light oscillation:

$$L_n = \frac{2}{b}\sin\left(bp + \frac{n\pi}{2}\right) J_n(bq)\sin\omega t \quad .\;. \quad (9)$$

The distinction between the diffraction pattern now obtained and the original one consists in the fact that the width p of the zero track, which with unilateral modulation (see 7*a*) occurs only in the phase of the light oscillation (except in the zero order with which we are not further concerned), now enters the amplitude, and is therefore expressed in the intensity distribution. It causes thereby, as fig. 2 also shows, a series of equidistant zero points and maxima in each line, which alternate for neighbouring orders, since according to (9) they are determined for even orders by sin bp and for odd orders by cos bp.

We must therefore conceive these extra zero points and maxima as the result of the interference of the two diffraction spectra, which are projected by the upper and lower parts, respectively, of the track.

This phenomenon permits us to determine the quantities p and q separately from the spectrum, since they are present independent of each other. If the width of the zero track is changed with q remaining the same, the distance between the p zero points changes, while the St Andrew's cross retains its shape. If the depth of modulation is changed while the width of the zero track remains the same, the slope of the arms of the cross changes, while the p zero points retain the same separation.

On the horizontal axis, according to the above-mentioned proposition, we may again only expect the zero and first order. We find

$$A_0 = 2p$$
$$A_1 = q$$
$$A_2 = A_3 = A_4 = \dots = 0.$$

The diffraction pattern of obliquely recorded film

No matter how much the sound track may be deformed by oblique recording, it still remains periodical with the same period l. As we have explained in the discussion of the perforated grating, the diffraction pattern will therefore consist solely of vertical lines in their old positions a_n. No new lines occur, only the intensity distribution of each line in the vertical direction will be changed.

Oblique recording in our method of building up the sound track amounts to the fact that we must begin with a slit grating whose slits make a certain angle ψ with the vertical axis [9]).

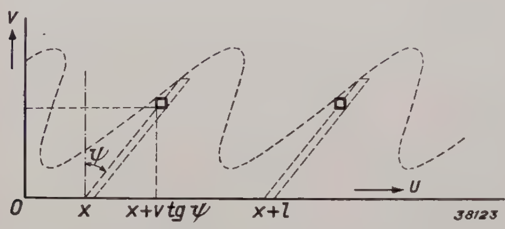

Fig. 12. An obliquely recorded sound track may be built up of gratings of oblique slits (angle ψ). The diffraction pattern of such a slit grating can be derived in the same way as above, by integrating over perforated gratings. The perforated gratings lying one above the other must then be shifted with respect to each other according to the condition $\mu = x + v \tan \psi$.

We now attempt to derive the diffraction pattern of this slit grating from that of the perforated grating. The perforated grating at the height v must now also be provided with another u coordinate, namely by the replacing of x by $x + v \tan \psi$ (see *fig. 12*). The light oscillation (4a), when we indicate the coordinates of the new diffraction spectrom by α' and β', thus becomes

$$\frac{1}{l} \sin \left\{ \omega t + \frac{2\pi\alpha'}{\lambda} x + \left(\frac{2\pi\alpha'}{\lambda} \operatorname{tg} \psi + \frac{2\pi\beta'}{\lambda} \right) v \right\} \mathrm{d}x \, \mathrm{d}v$$

or

$$\frac{1}{l} \sin \left\{ \omega t + \frac{2\pi\alpha}{\lambda} x + \frac{2\pi\beta}{\lambda} v \right\} \mathrm{d}x \, \mathrm{d}v, \quad . \quad . \quad (4c)$$

where

$$\left. \begin{aligned} \alpha &= \alpha', \\ \beta &= \beta' + \alpha' \operatorname{tg} \psi. \end{aligned} \right\} \quad . \quad . \quad . \quad . \quad . \quad (10)$$

With this the solution of our problem is already complete. Equation (4c) is absolutely identical with equation (4a), so that with it, upon passing on to the slit, the sine, etc., we derive exactly the same diffraction patterns as for the vertically recorded films. The only difference is that the coordinates α and β must be replaced by α' and β' by the use of equation (10), which amounts to an oblique angular transformation of the normal diffraction pattern, in which the vertical lines remain vertical and the horizontal lines are rotated through an angle ψ (*fig. 13*). With this therefore we have deduced the behaviour of the diffraction pattern of obliquely recorded film already described in our general consideration.

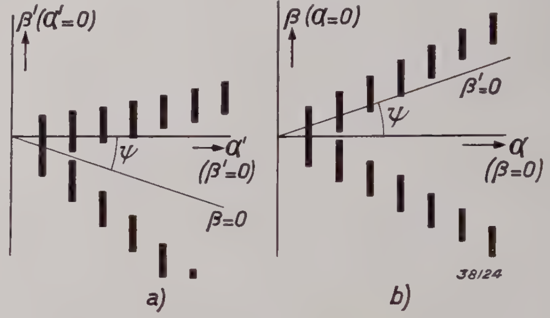

Fig. 13. Transformation experienced by the diffraction pattern when the sound track is recorded obliquely. All the vertical lines in the pattern remain vertical, all the horizontal lines are rotated through an angle $\psi(\alpha)$. In order to find the new acoustic spectrum, therefore, the old diffraction pattern (with vertical slit) may be used by rotating the "horizontal axis" through an angle ψ (b).

This may be further illustrated by means of the model of the function $|J_n(\xi)/\xi|$, which was reproduced in fig. 10. The different functions which are cut out of paper are mounted in separate wooden strips. The spectrum of the obliquely recorded film is now obtained (*fig. 14*) by sliding the strips along each other. It is clear how the second and third orders now slide across the horizontal axis (the celluloid plane) and thus appear in the Fourier spectrum of the sound obtained upon reproduction.

The diffraction pattern of the normal true sine, which until now was of no acoustic interest outside the horizontal axis, now takes on full significance, since it is to be considered as a complete model of the Fourier spectra which will be obtained at any given angle of recording or reproduction. The new "horizontal axis" $\beta' = 0$ is found in the normal dif-

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[9]) The obliquely recorded film may be considered to be formed from the vertically recorded film by an oblique angular transformation in which the horizontal lines have remained horizontal and the vertical lines have been rotated through an angle ψ.

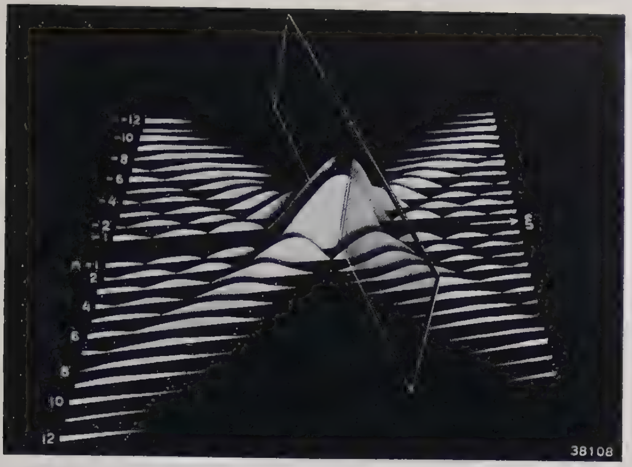

Fig. 14. The model shown in fig. 10 is so constructed that the strips of paper which represent the light distribution along the lines of the diffraction pattern can be shifted along each other. In this way the transformation shown in fig. 13 can be demonstrated.

fraction pattern according to (10) as a straight line through the origin

$$\beta = a \operatorname{tg} \psi \quad . \; . \; . \; . \; . \; . \quad (11)$$

The values of the amplitude of the light of the different orders on this line give us the coefficients of the different higher harmonics.

We shall now carry out this calculation numerically for several practically important cases.

The Fourier spectrum upon oblique recording or reproduction

Unilateral modulation

The amplitude of the light oscillation upon diffraction by a unilaterally modulated sine track is, according to (7a) proportional to

$$A_n = \frac{1}{b} J_n(bq) . \; . \; . \; . \; . \; . \; . \; . \quad (12)$$

If in (11) we again write $2\pi\beta/\lambda = b$ and $a = n\lambda/l$ and express the period l in the frequency ν and the film velocity c ($c = \nu l$), (11) becomes

$$b = \frac{2\pi n \nu}{c} \operatorname{tg} \psi \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (13)$$

For small angles ψ, thus for small values of bq, in the series of the Bessel functions the first term is sufficient, and tan ψ may be replaced by ψ. We then obtain

$$A_n = \frac{b^{n-1}\, q^n}{2^n \cdot n!} = \frac{q}{2 \cdot n!} \left(\frac{\pi n q \nu \psi}{c}\right)^{n-1},$$

thus for the separate amplitudes A_n and for the relative amplitudes B_n, referred to the fundamental frequency:

$$A_1 = \frac{q}{2}, \qquad B_1 = \frac{A_1}{A_1} = 1,$$

$$A_2 = \frac{\pi q^2}{2c} \nu\psi, \qquad B_2 = \frac{A_2}{A_1} = \frac{\pi q}{c} \nu\psi,$$

$$A_3 = \frac{3}{4} \frac{\pi^2 q^3}{c^2} \nu^2\psi^2, \qquad B_3 = \frac{A_3}{A_1} = \frac{3}{2} \frac{\pi^2 q^2}{c^2} \nu^2\psi^2 = 1{,}5 \; B_2^{\,2},$$

$$A_4 = \frac{4}{3} \frac{\pi^3 q^4}{c^3} \nu^3\psi^3, \qquad B_4 = \frac{A_4}{A_1} = \frac{8}{3} \frac{\pi^3 q^3}{c^3} \nu^3\psi^3 = 2{,}33 \, B_2^{\,3}.$$

It may therefore be seen that the amplitude A_1 of the fundamental frequency is independent in the first approximation of the frequency ν and the angle ψ. The relative intensity B_2 of the second harmonic is directly proportional to the sound amplitude q and to ν and ψ, the third harmonic to the square of these quantities, etc. We are therefore concerned with a non-linear distortion which increases rapidly with the frequency. This distortion is independent of the width p of the zero track. For small angles the higher harmonics may be neglected compared with the second harmonics, so that we need only deal with the latter.

If we assume a film velocity of 320 mm/sec and an amplitude q of 1.0 mm, and if we express the frequency ν in kc/s and the angle ψ in minutes,

$$B_2 = 0{,}29 \, \nu\psi \; \% \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (14)$$

The fundamental frequency is indeed independent of ψ in the first approximation used until now, but its amplitude will decrease in the second approximation as the model (fig. 14) also shows. Here also the quantity $q\nu\psi$ is the determining factor. In sound film practice therefore the correct position of the light slit is checked by recording the frequency 8 000 c/s and by adjusting the slit for reproduction so that a maximum sound intensity is obtained. The accuracy of this adjustment, particularly in unilateral modulation, may be seen from the following example. It is for example required that the second harmonic should not be stronger than 3 per cent at 4 000 c/s. This means according to (14) an angle ψ of $2^1/_2$ minutes. From *fig. 15*, curve *a*, it then follows that upon adjustment with the frequency 8 000 c/s the amplitude of the fundamental frequency may not deviate more than 0.15 per cent from the maximum value.

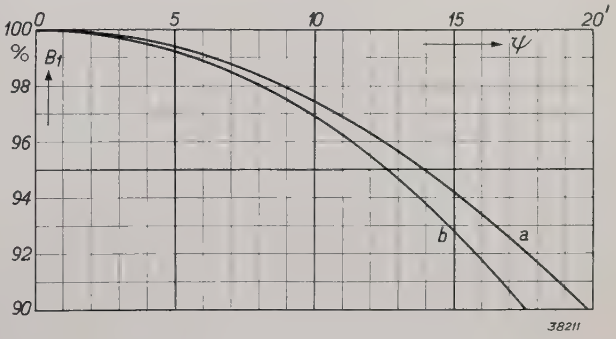

Fig. 15. Amplitude of the fundamental tone of the sound which is obtained upon oblique scanning of a sinusoidal sound track, as a function of the angle ψ of the slit. The curve *a* is for unilateral, *b* for bilateral modulation (frequency ν = 8 000 c/s, depth of modulation 100%, zero track width 1.0 mm, film velocity 320 mm/sec).

Bilateral modulation

The amplitude of the light oscillation upon diffraction by a bilaterally modulated sine track is, according to (9),

$$A_n = \frac{2}{b} \sin\left(bp + \frac{n\pi}{2}\right) J_n(bq).$$

For odd orders this amplitude is the same as the one just dealt with, because for small angles cos bp may be considered equal to unity. For even orders, however, a multiplication factor sin bp occurs, so that the zero track width p now begins to play a part. For small angles ψ we find

$$A_1 = q, \qquad B_1 = \frac{A_1}{A_1} = 1,$$

$$A_2 = 4\,\frac{\pi^2 pq^2}{c^2}\,\nu^2\psi^2, \qquad B_2 = \frac{A_2}{A_1} = 4\,\frac{\pi^2 pq}{c^2}\,\nu^2\psi^2,$$

$$A_3 = \frac{3}{2}\,\frac{\pi^2 q^3}{c^2}\,\nu^2\psi^2, \qquad B_3 = \frac{A_3}{A_1} = \frac{3}{2}\,\frac{\pi^2 q^2}{c^2}\,\nu^2\psi^2 = 0{,}375\,\frac{q}{p}\,B_2,$$

$$A_4 = \frac{64}{3}\,\frac{\pi^4 pq^4}{c^4}\,\nu^4\psi^4, \qquad B_4 = \frac{A_4}{A_1} = \frac{64}{3}\,\frac{\pi^4 pq^3}{c^4}\,\nu^4\psi^4 = 1{,}33\,\frac{q}{p}\,B_2^2.$$

The second harmonic has now become proportional to the square of the frequency ν and the angle ψ, and has therefore fallen to about the same level as the third harmonic. Bilateral modulation is therefore considerably more satisfactory than unilateral modulation[10]) as far as this distortion is concerned. The case may be so conceived, that the upper and lower part of the track are, as it were, in push-pull connection, so that the even harmonics are suppressed in the first approximation.

If we assume a total zero track width $2p = 1.0$ mm and a depth of modulation of 100 per cent

$$B_2 = 0{,}0009\,\nu^2\psi^2\,\% \quad \ldots\ldots\ldots \quad (15)$$

If we now again require a maximum distortion at 4 000 c/s of 3 per cent, the maximum permissible angle $\psi = 15$ minutes, which condition, according to fig. 15, curve *b*, can be satisfied by adjusting the amplitude of the fully modulated tone 8 000 within 7 per cent of the maximum.

In *fig. 16* the percentage of second harmonic is given as a function of the angle ψ and the frequency ν for unilateral and bilateral modulation.

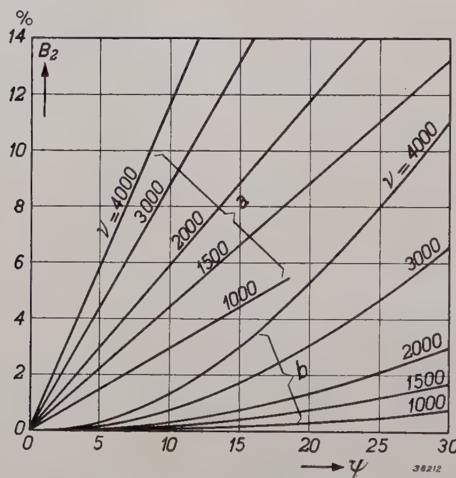

Fig. 16. Percentage B_2 of second harmonic as a function of the angle ψ of the slit for different frequencies ν. The group of curves *a* holds for unilateral, the group *b* for bilateral modulation (depth of modulation 100%, zero track width 1.0 mm, film velocity 320 mm/sec). It may be seen that in the latter case the reproduction is much less sensitive to slight deviations from the vertical position ($\psi = 0$) of the slit.

The diffraction pattern of two frequencies

When two frequencies ν and μ with amplitudes q and r, respectively, are recorded on the film, then the following is valid for y:

$$y = p + q\cos\frac{2\pi\nu}{c}\,x + r\cos\frac{2\pi\mu}{c}\,x,$$

where c is the film velocity in recording and reproduction. This also may always be interpreted as a periodic phenomenon, with a period which is equal to the smallest common multiple of the periods c/ν and c/μ. The calculations, which we shall not go into here [4]), may then take place quite analogously to the case of a single frequency. It is found that for angles α only lines can occur which satisfy the following:

$$\frac{c\,\alpha_{n,m}}{\lambda} = n\nu + m\mu, \quad \ldots\ldots \quad (16)$$

where n and m are positive or negative whole numbers. Besides the higher orders $n\nu$ and $m\mu$, therefore, all the intercombination lines occur.

With bilateral modulation the light oscillation is

$$L_{nm} = \frac{2}{b}\sin\left(bp + \frac{n+m}{2}\pi\right) J_n(bq)\,J_m(br)\,\sin\omega t \quad \ldots \quad (17)$$

This is therefore determined by products of Bessel functions.

In *figs. 17a* and *18a* two typical examples are reproduced. Fig. 17*a* shows the diffraction pattern of a sound track with two only slightly differing frequencies ($\nu = 1\,600$, $\mu = 1\,880$ c/s), fig. 18*a* the diffraction pattern for two frequencies far apart ($\nu = 1\,600$, $\mu = 210$ c/s). Figs. 17*b* and 18*b* show the diffraction patterns for the same combinations of frequencies, but in this case for obliquely recorded film. As was to be expected, the patterns have remained the same except for the oblique angular transformation. Since the normal pattern also contains all the intercombination lines outside the horizontal axis, they will occur in the sound upon reproduction with an oblique slit as combination tones, and to a greater degree the higher the order of the lines in question (the higher the frequency) and the closer to the horizontal axis they reach their first maximum.

The calculation of this non-linear distortion is quite analogous to that with one frequency. We shall deal with one case as an example, namely the intensity of a low difference frequency of two high parent frequencies. The two high parent frequencies will be much distorted. What is now the magnitude of the difference frequency? Is it of the same order as the two second harmonics, or much smaller? The amplitude of the light oscillation in the diffraction spectrum, according to (17) is

$$A_{nm} = \frac{2}{b}\sin\left(bp + \frac{n+m}{2}\,\pi\right) J_n(bq)\,J_m(br).$$

The difference tone is obtained by setting $n = -1$

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[10]) M. C. Batsel and E. W. Kellogg, J. Soc. Mot. Pict. Eng. 28, 516, 1937.

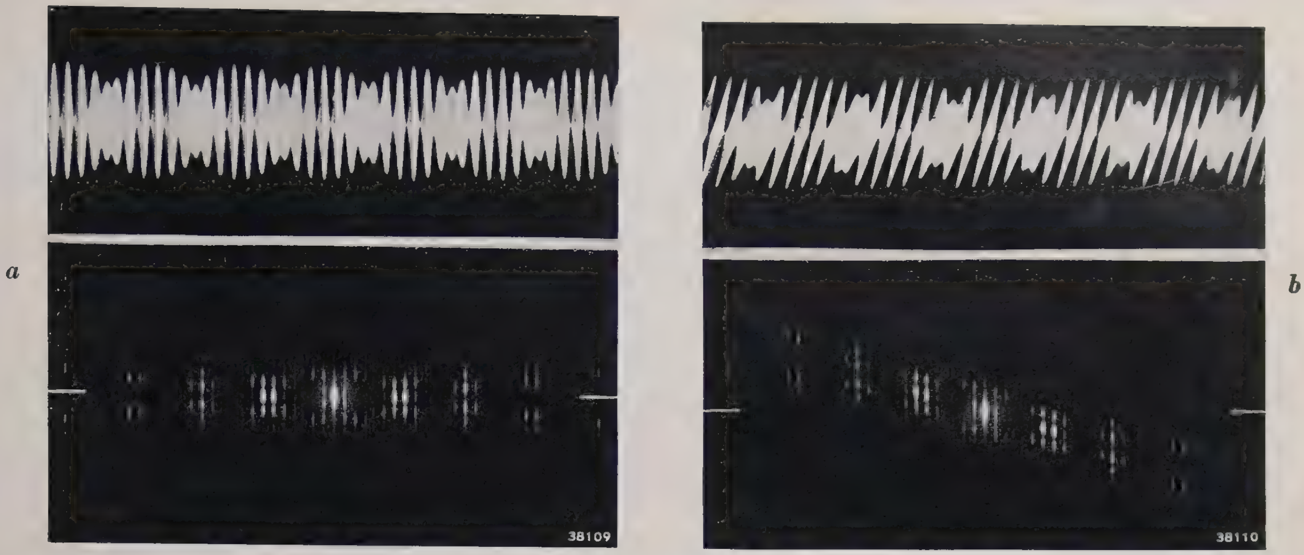

Fig. 17. Sound track with two different frequencies ($\nu = 1\,600$, $\mu = 1\,880$ c/s) and corresponding diffraction pattern, *a*) for recording with vertical slit, *b*) for recording with oblique slit ($\psi = 15°$). In (*a*) only the frequencies 0, 1 600 and 1 880 should be visible on the horizontal axis. The difference tone 280 is, however, also clearly visible, which indicates that a non-linear distortion was already present in the sound recorded.

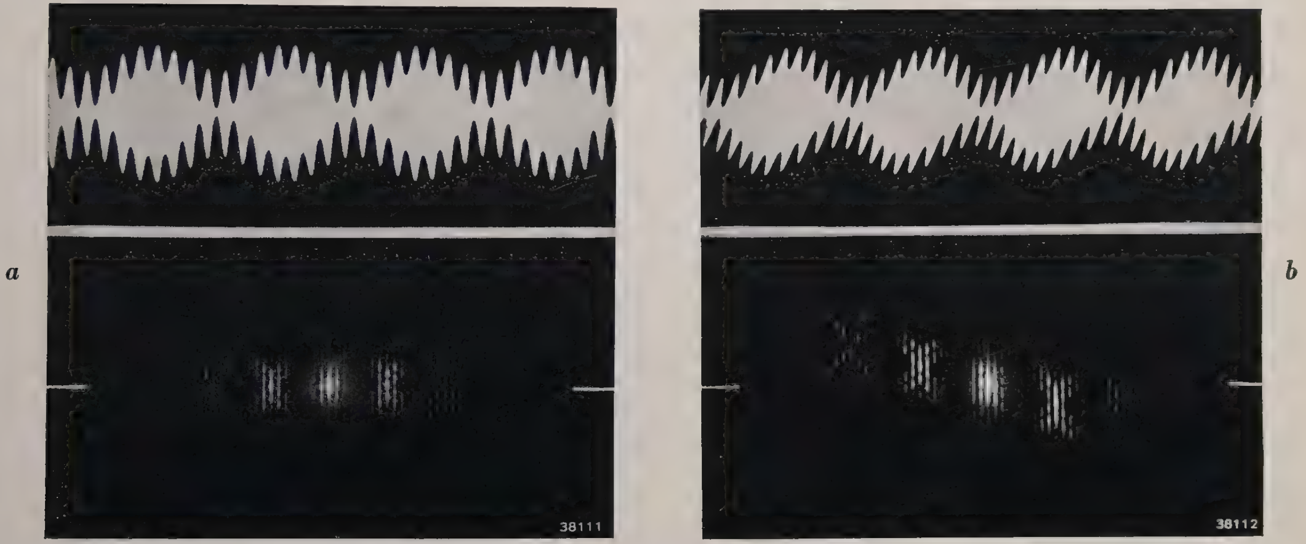

Fig. 18. The same as in fig. 17 but for two frequencies lying far apart ($\nu = 1\,600$, $\mu = 210$ c/s). Again *a*) was recorded with vertical slit and *b*) with oblique slit. Here also the recorded sound was already distorted, as may be seen from the fact that in (*a*) on the horizontal axis the sum and difference frequencies 1 810 and 1 390 and the second harmonic 3 200 are visible.

and $m = +1$, which gives as a first approximation:

$$A_{-1,+1} = -\frac{2}{b}\,bp\,\frac{bq}{2}\cdot\frac{br}{2} = -\frac{b^2pqr}{2}\,.$$

Now according to equation (11) the value of b which corresponds to the intersection with the "horizontal axis" is always proportional to a, thus, according to (16) proportional to the difference frequency $\mu-\nu$ formed. The amplitude of the difference tone is therefore proportional to $(\mu-\nu)^2$.

We thus encounter a very remarkable kind of frequency-dependent non-linear distortion, in which the intensity of the combination frequencies formed is independent of the height of the parent frequencies and determined only by the height of the frequencies formed. If the difference frequency is low, it occurs only weakly, even though the two parent frequencies are both very much distorted.

A TELEPHONE INSTALLATION ON ULTRA SHORT WAVES FOR THE TROPICS

by C. G. A. von LINDERN.

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For telephone communication in tropical and subtropical regions Philips have developed a transmitting and receiving installation which works on wavelengths of about 4 m. By the use of directional aerials a distance of from 50 to 100 km can be bridged with a transmitting power of 40 W if the transmitting and receiving installations are situated at sufficiently great altitudes, as on mountain tops. With this latter condition in view the installation is arranged for operation from a distance, while at the same time all precautions have been taken to protect the transmitter against the dangers involved in being set up in the open in a tropical climate. After a short description of the construction of the transmitter, the precautions mentioned are dealt with in detail. These are embodied in all kinds of structural particulars of the transmitter. In conclusion the operation from a distance of the installation is discussed.

For the telephonic bridging of oceans or extensive regions which are thinly populated it is usually simpler to achieve a radio connection than a cable connection; with very great distances the radio connection is indeed the only possibility. But even when it is a question of short distances, of only 50 or 100 km, for instance, under certain circumstances a radio connection may be preferable to a cable connection. Such conditions occur especially in tropical and subtropical regions: jungle, swamps and deserts in this case seriously hamper the installation of overhead wiring or the laying of cables, while, moreover, the cable connection always remains very vulnerable due to climatological conditions, and is accessible only with difficulty for any necessary repairs.

For such cases a radio connection on ultra short waves below 5 m is indicated. We shall describe an installation designed for this purpose, in which particular attention has been paid to the requirements made of the construction in a tropical climate.

The general design

The ultra short waves below 5 m have only a limited sphere of action with the output which may be used in practice: roughly speaking these waves are not propagated much farther than the distance of optical visibility. For the cases here under consideration, however, this is no objection, since it is only a question of relatively short distances which, when the transmitting and receiving aerials are mounted at great enough altitudes, make the two stations visible to each other. On the other hand the use of waves shorter than 5 m offers special advantages. In the first place in this wave-length region numerous transmitters may be used without their frequency ranges interfering with each other, an advantage which is further increased by the above-mentioned limitation of the sphere of action, since this makes it possible to use a given wave length several times in the same district. The great freedom in the frequency range can also be used to give the transmitter and receiver a band width such that a number of conversations can be transmitted simultaneously in different channels of the side bands (carrier-wave telephony). In the second place, with respect to transmitting energy also, short waves have advantages over longer waves. While it is indeed more difficult to generate large transmission outputs on short waves, there is the possibility of concentrating the energy emitted in a beam. At a wave length of 4 m with a directional aerial of reasonable dimensions a tenfold amplification of the energy radiated in a given direction can be obtained (of course at the expense of the energy radiated in other directions). For the case in question where the radio connections form part of a telephone network, and where, therefore, several of such radio connections must be connected in series, a signal intensity at the receiver must be required which is at least 50 dB above the normal interference level (noise). By the use of directional aerials (at the receiving end also) this signal to interference ratio, at a distance of 50 km, for example, and with the use of the best receiving valves available at the present time, can already be obtained with a transmission output of 30 to 40 W.

We have already mentioned that it is necessary to mount the aerials of transmitter and receiver at a great altitude, a mountain top for instance, in order to obtain the direct "line of vision". Since the supply line for the aerial must be short, the transmitter and receiver must be in the immediate neighbourhood of the aerials, while the telephone exchange where the radio connections terminate may in general be at some distance, in the valley for instance. This has two consequences: the transmitter and receiver must in general be set up in the open and work without attention, and the switching on of the apparatus must be able to take place from a distance. In the following there will be opportunity of discussing the consequences which these conditions lead to in the construction of the system.

In *fig. 1* the situation described is sketched simply. For transmitter and receiver directional aerials may be used which consist of a number of parallel rods mounted one behind the other. For the conversations in the two directions a slightly different wave length is used in order that the receiver of each station will not be affected by the transmitter of the same station.

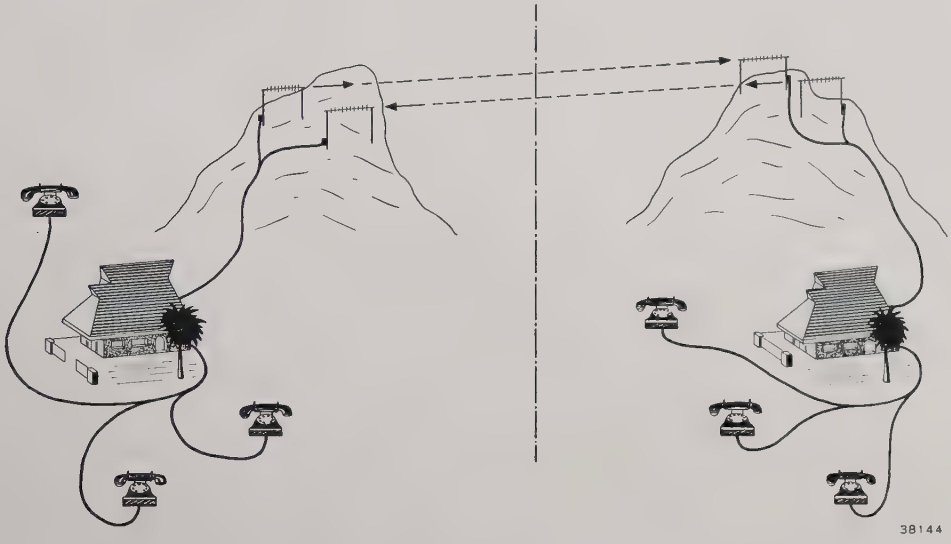


Fig. 1. Sketch of the arrangement for the radiotelephonic connection. In the neighbourhood of each of the two telephone exchanges to be connected the transmitter and the receiver with their directional aerials are set up at a high altitude. Each installation is connected to the corresponding telephone exchange by means of a telephone line and a power cable for the supply.

Connections of the transmitter

The transmitter proper consists of three stages: an oscillator stage which furnishes a high-frequency oscillation of small amplitude but with a constant frequency in the neighbourhood of 75 Mc/s (4 m wave length), an intermediate stage and an output stage in which the oscillation is amplified to an output of 40 watts. The frequency of the oscillator stage, which contains two pentodes PE 06/40 in push-pull connection, is determined by a so-called long line. This is a concentric cable short circuited at one end and open at the other. If the length of the inner conductor is l, with oscillations of the wave length $4l$, or $4l/3$ or $4l/5$ etc. resonance occurs, *i.e.* only for these wave lengths does an appreciable alternating magnetic field between the two conductors occur. The back-coupling of the anode circuit, roughly tuned to $\lambda = 4l$ by coils and condensers, on the grid circuit of the oscillator is now achieved *via* the above-mentioned alternating magnetic field, see *fig. 2*. Only those oscillations with the wave length λ are then built up and maintained.

The resonance curve of the long line is sharper, *i.e.* the frequency of the transmitter is more constant, the fewer the dielectric and other losses occurring in the long line. The dielectric losses in our case are practically zero, since the concentric "cable" is built up entirely without solid insulating materials: the outer conductor is a strong copper cylinder 25 cm in diameter, the inner conductor a rod of 5 cm diameter and 1 m length inside the former, and entirely free of it. The losses by radiation and induction in the surroundings are rendered very small by making the outer conductor somewhat longer than the inner conductor and shutting it off completely (*fig. 3*).

Due to the coupling with anode and grid circuit of the oscillator valves, the characteristic frequency of the long line is to some degree affected by the rest of the connections. This undesired influence is kept small by not making the coupling too firm, and by including only a small anode impedance in the oscillator. This all means that only a small high-frequency output can be obtained. The amplification of the high-frequency oscillation in intermediate and output stage takes place with triodes TE 05/10 and TB 1/60, respectively, whereby the undesired reaction of the anode on the grid circuit caused by the anode-grid capacity is eliminated with neutrodyne condensers.

Modulation is accomplished by changing the

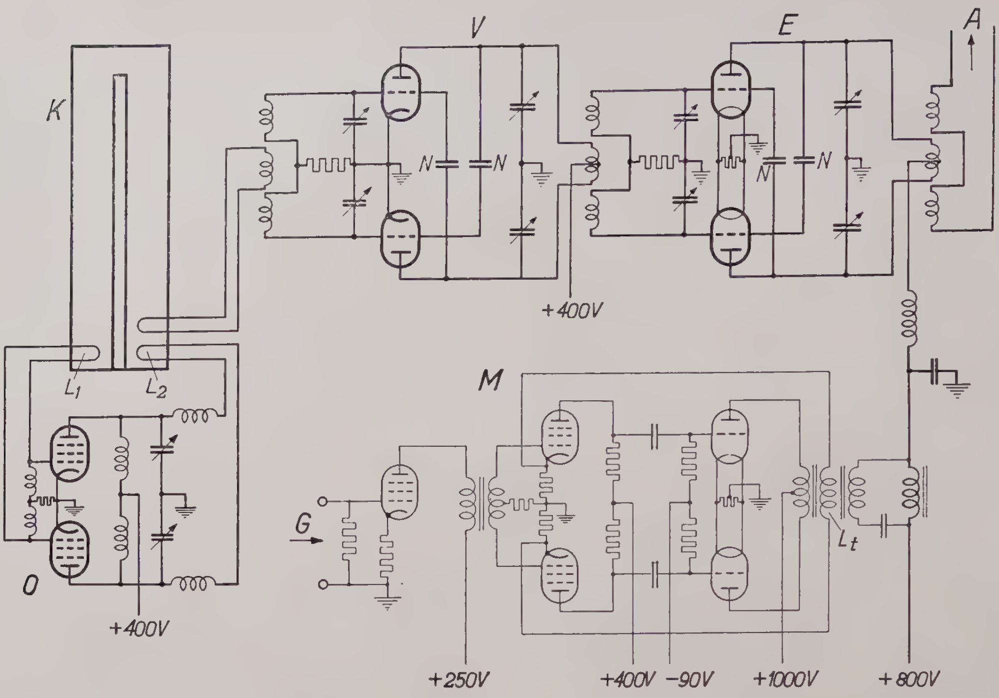


Fig. 2. Connections of the transmitter (simplified). The backcoupling of anode circuit on grid circuit of the oscillator *O* takes place through coils L_1, L_2, which are within the alternating magnetic field of the "long line" *K*. *V* intermediate amplifier stage, *E* output stage, *N* neutrodyne condensers, *A* aerial, *M* modulator. Modulation is accomplished by changing the anode voltage of the output stage. The modulating voltage entering at *G* is amplified in three stages; the coil L_t provides a tenfold inverse feed-back.

anode voltage of the final stage (fig. 2). The microphone voltages coming in over the line from the telephone exchange are amplified in three stages, so that it is possible to modulate the transmitter fully with a low-frequency input power of only $^1/_4$ milliwatt (an ordinary telephone apparatus provides 1 mW, so that the telephone line to the transmitter may cause an additional attenuation of 6 dB, *i.e.* by a factor of 4). The frequency region of the modulator lies between 300 and 50 000 c/s for the first installation constructed, *i.e.* in this region the amplification factor remains constant within 2 dB, while the non-linear distortion with full load amounts to less than 1 per cent. This latter is obtained by a tenfold inverse feed-back. The broad frequency band, as was already mentioned at the beginning, permits telephony on a number of channels at the same time. If desired the modulator can be constructed for a still much wider frequency region having a width of several 100 kc/s without great difficulty.

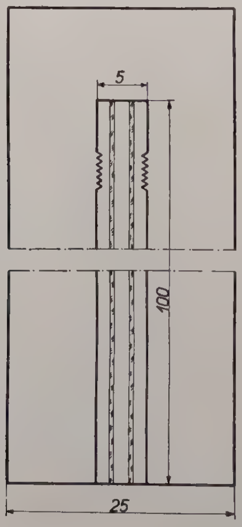


Fig. 3. Construction of the long line. It consists of a copper cylinder 25 cm in diameter in which a copper conductor 5 cm in diameter is fastened concentrically. The length of the inner conductor determines the wave length of the characteristic oscillation of the whole.

As to the supply of the transmitter, it is assumed that there is a 220 volt A.C. main at the telephone exchange, to which the transmitter can be connected. The necessary rectifiers are therefore introduced into the transmitter in order to obtain the anode voltages, heating currents, etc. from the main. If no mains connection is available, as may sometimes be the case in places far from civilization, a petrol aggregate must be used for generating the current.

Construction of the transmitter

A transmitter which must function in a tropical climate and, moreover, in the open and without supervision, is exposed to many kinds of dangers.

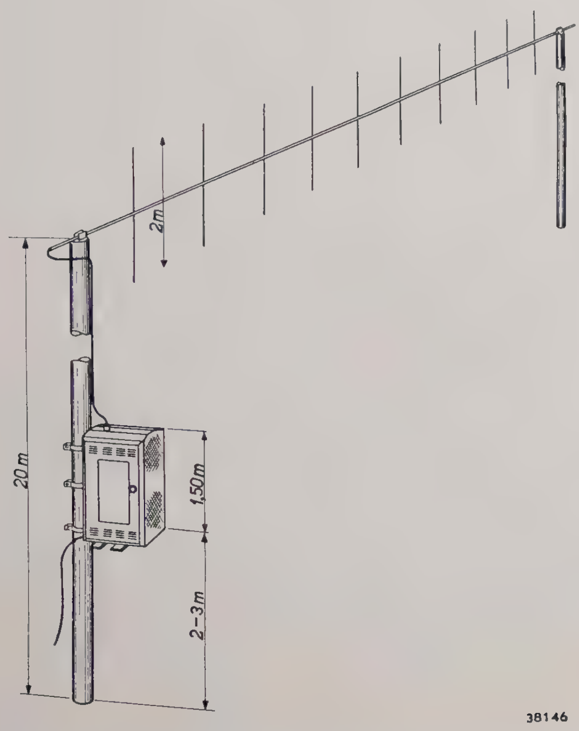
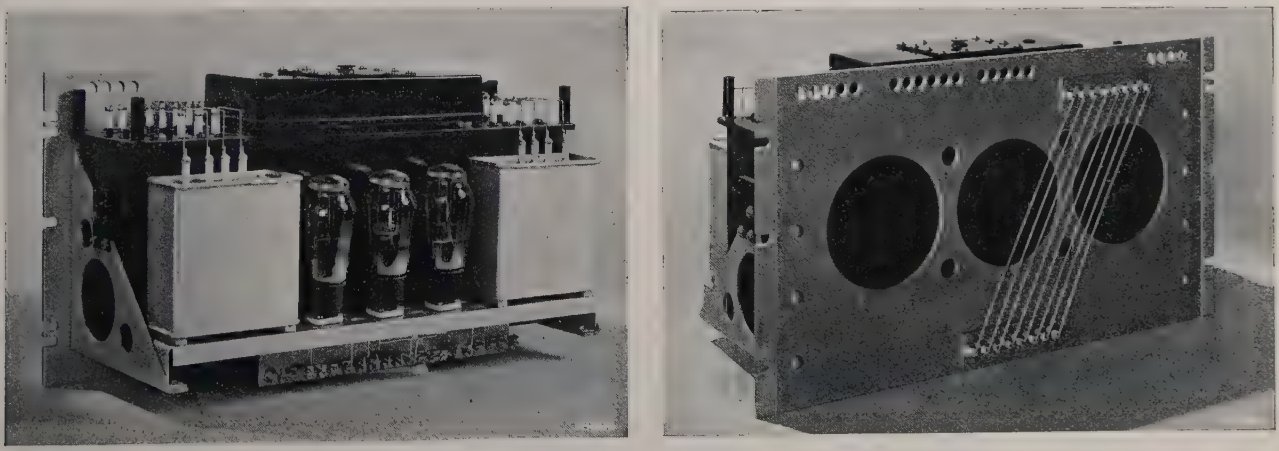


Fig. 4. The transmitter is enclosed in a strong closed case which is hung several metres above the ground on one of the 20 m high aerial poles.

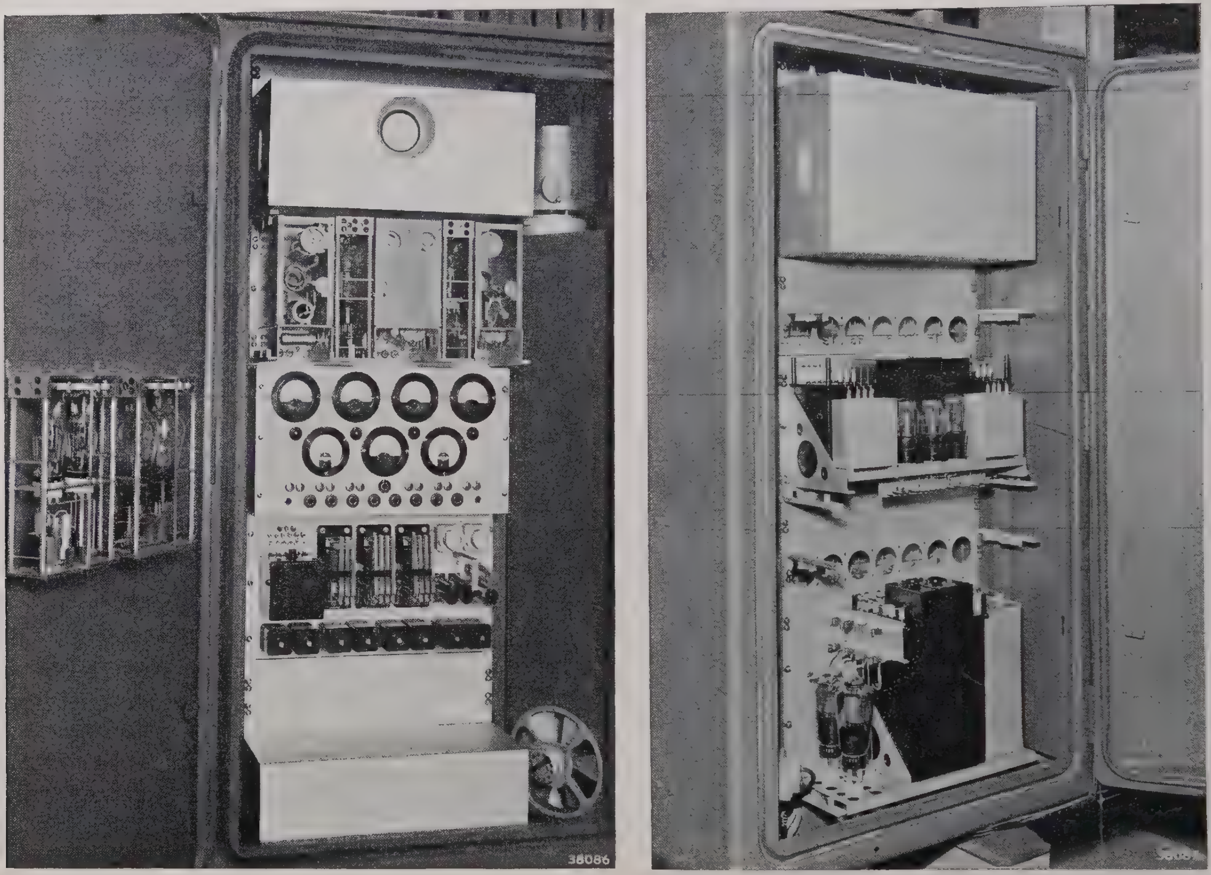
It is protected against rain and sand by being enclosed in a strong tight case which is hung several metres above the ground on an aerial mast to remove it from the undesired attentions of the uninitiated and of all kinds of animals (*fig. 4*). A second danger ready to attack the transmitter are various kinds of fungi and the white ants so feared in the tropics. If it is not possible to seal the case by soldering it —which is of course the case here, since it must be opened once in a while for inspection and repair — there is only one sure method of preventing damage by these insects: in constructing the transmitter all materials must be avoided which could possibly stimulate the appetites of white ants and the like. This means in the first place that no textile or similar material may occur as insulation for the wiring; the wiring is thus bare and is supported by small insulators of high-frequency porcelain. Where "edible" insulation materials were unavoidable, as in the windings of the transformers, and chokes of the supply apparatus, the parts are housed in sealed oil containers with porcelain leads soldered in, see *fig. 5*. At the same time the temperature increase of the windings is hereby decreased which is doubly welcome in connection with the third great difficulty encountered in the tropics: the high temperature of the surroundings. This latter is particularly unpleasant, since the cooling of the transmittter is made difficult by the closed case which may not even contain any ventilation openings. In order to promote the dissipation of the heat developed in the case — the transmitter consumes 660 W — the walls and doors are made of double plates between which the outside air can circulate. In this way a larger surface takes part in the transmission of heat to the outside. In the case itself local overheating is avoided by a forced air circulation by means of fans. This necessitated a favourable arrangement of the different parts of the transmitter. In *fig. 6* the arrangement may be seen. The long line is placed vertically along one side, and above it the oscillator stage. In the middle of the case is a frame, to the front and back



a *b*

Fig. 5. Panel with supply apparatus *a*) front, *b*) back. The large container filled with oil contains the transformers and choking coils. On top of the container is an expansion chamber. Smoothing condensers are mounted in the boxes on either side of the rectifier valves. The wiring is bare, all leads through are made of high-frequency porcelain. The large holes in the rear wall of the panel promote the air cooling.

of which, both accessible by means of doors, a number of panels are fastened which contain the other stages of the transmitter, the supply apparatus, measuring instruments, switching arrangements, etc. The frame with its panels is separated from the long line by a partition; the fans which cause the air to flow upward along the panels and down along the long line are set into this partition.



a *b*

Fig. 6. Transmitter case with opened doors. At the front (*a*) may be seen to the right the partition which shuts off the long line and above the latter the oscillator stage. In addition a number of panels which contain (from top to bottom): a cathode ray tube, intermediate and output stage, measuring instruments, relays and switches. On the door are two reserve units. At the back (*b*) may be seen three panels (from top to bottom): the modulator, the supply apparatus for the heating voltages and the anode voltages of the first stages of transmitter and modulator, and the large supply apparatus for the anode voltage (1 000 volts) of the output stages of transmitter and modulator. Through the ventilation holes the wiring lying in the frame may be seen.

Thanks to these measures the temperature of all the parts is limited to a maximum of 70 °C at a temperature of the surroundings of 45 °C.

We shall now discuss several details of the construction.

The construction of the long line has already been discussed to some extent in the foregoing, and it was pointed out that the frequency is determined by the length of the inner conductor. Now this length changes due to the expansion of the material upon increase in temperature. If simply a copper rod with a coefficient of expansion of 162×10^{-7} were taken as inner conductor, upon a temperature change of 20° the length would vary by 0.032 per cent, which, with a wave length of 4 m would mean a shift of the carrier-wave frequency by about 24 000 c/s. In order to combat this very undesired effect the inner conductor is made of a tube of quartz over which a thin covering of copper is slid. The covering consists of two sections which are fastened to the ends of the quartz tube and connected with each other by an intermediate section which is extensible like an accordion, see fig. 3. The result is a copper rod whose length is as it were determined by the quartz tube. The coefficient of expansion of quartz is only 6×10^{-7}, so that the same calculation as above now gives a variation of only 900 c/s.

Since the grid-anode capacity of the triodes which are used in the intermediate and output stages of the transmitter may be somewhat different for different valves, upon changing defective valves the neutrodyne condensers must be adjusted anew. In order that this may also be done by unskilled personnel, two complete reserve units are hung on the inside of the door of the transmitter (see fig. 6*a*), which units are neutrodyned in advance, and can simply be slid into the place of the old units in the corresponding openings of the panel involved. The necessary connections are automatically made by a set of contacts. In *fig. 7* the reserve units are shown separately. It may be seen that the connection between the valves and the other parts of the circuit have been kept very short, which is desirable in connection with the high transmission frequency. The neutrodyne condensers, which are clearly visible in the right-hand unit in fig. 7, consist of two plane parallel metal discs which are held apart by porcelain rods. The distances between the condenser plates, as well as between other points between which high-frequency voltages act 1), are so chosen that even in mountainous districts, where due to the decreased atmospheric pressure and other causes the breakdown voltage may be considerably lower than at sea level, no breakdowns can occur.

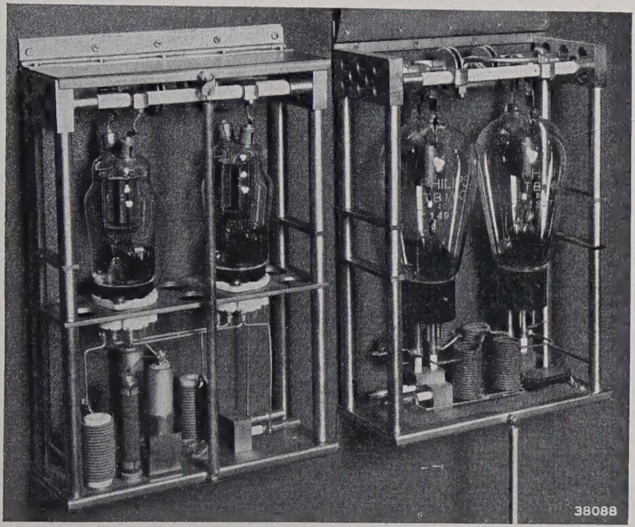


Fig. 7. Complete reserve units neutrodyned in advance. To the left for the intermediate stage, to the right for the output stage. These units can be slid into appropriate openings in the transmitter panel (fig. 6*a* second from the top).

The oil containers in which the transformers, etc. are housed have an expansion chamber in which the excess oil is driven when the liquid expands due to the heat (at 50° temperature difference the change in volume amounts to about 5 per cent). In order to prevent the oxidation of the oil as far as possible the expansion chamber is so constructed that the surface of contact between air and oil is small. Upon cooling, the oil runs back, and in doing so draws in a quantity of fresh air. Since in tropical climates the air is always very moist, and this is particularly undesirable for keeping the oil in good condition, the air as it flows into the container is made to pass a long distance over a drying agent (silica gel).

In order to make the necessary connections between the panels there is a horizontal strip with porcelain leads behind every panel, at which the bare wiring lying in the frame terminates and to which the panel is connected. As far as possible the connections on the strips are so arranged that the bare wires do not cross each other. Where crossings were unavoidable, they are concentrated in two of the horizontal strips: these strips are constructed as closed cans in which the connections between the leads on one side (toward the panel) and the other sides (to the frame) may cross each other as much as is necessary, since the can is later filled with a so-called tropics compound, a pitchlike insulation material with a high softening point. The can is then sealed by soldering. Particular attention must be paid to the earth connection with the high frequency used here. A very good electrical contact between the chassis of the panels and the frame is essential. This is obtained by applying the Schoop process to the overlapping edges of panel and frame 2).

The receiver

On the subject of the receiver we may be brief. It is a superheterodyne apparatus with an intermediate frequency of about 3 Mc/s and a band width of about 120 c/s (twice the maximum modulation frequency of the transmitter, increased by the amount by which the transmitter frequency may vary due to the abovementioned effects). The frequency of the auxiliary oscillator is here also kept constant by means of a long line. The reaction experienced by the long line from the rest of the connections is in this case much less than in the transmitter because of the much smaller powers

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1) With an anode D.C. voltage of about 800 volts (due to the high temperature of the surroundings the valves work with a decreased load, namely only 60 per cent of the permissible anode voltage, which is 1 200 volts) peak voltages of about 3 200 volts occur at full modulation.

2) In this process a firmly adhering layer of metal is deposited by spraying.

(smaller amplifier valves). The output of the receiver is adapted to the impedance of the line to the telephone exchange (normally 600 ohms) by a transformer.

The construction of the receiver is quite analogous to that of the transmitter. With the appurtenant supply apparatus it is assembled in the same kind of case as the transmitter, and the same considerations are valid for the wiring, etc. The heat problem was here much less serious of course, since the receiver consumes only 110 W.

The operation of the installation

The receivers of the two telephone exchanges in radiotelephonic connection must remain in action permanently during business hours, in order that any calls may be announced. The transmitter on the other hand will be preferably switched off after each call on lines which are not too busy. In order to be able to answer a call immediately, the transmitter must be able to be switched on in the shortest possible time. For this reason as far as possible valves with directly heated cathodes are used which are ready for use several seconds after being switched on. Where because of their more favourable properties (steeper slope, less hum, etc.) indirectly heated cathodes were specifically desirable, the cathodes are kept permanently heated. In order not to shorten the life of the cathodes, the anode voltages are only switched on 3 seconds later than the directly heated cathodes, and then at a value 25 per cent lower than the normal, which is only increased to the normal value after an additional 10 seconds. It is thus possible to speak 3 seconds after the transmitter has been switched on, although with a higher interference level for the first 10 seconds, since the lowered anode voltages involve a less favourable signal-noise ratio at the receiving end. The switching on in steps also limits the magnitude of the commutation current surges, so that the fuses introduced at various points can be smaller and the contacts suffer less wear.

The switching on of the transmitter in steps as mentioned takes place by means of a number of relays and bimetallic contacts, all of which are mounted on a panel in the transmitter case (see fig. 6*a*). The first relay, which switches on the receiver and all indirectly heated cathodes, is set in operation from the telephone exchange when the service begins by sending a direct current of 10 mA along the line to the transmitter. When a call is received the telephone operator switches her telemicrophone to this line, and the direct current mentioned is thereby automatically raised to 40 mA by an auxiliary contact. This sets in action a second relay in the transmitter which provides for the successive switching on of the directly heated cathodes, the diminished anode voltages and the normal anode voltages.

In a telephone network a signal with a frequency of 50 c/s or lower is usually used for calling, since the bells of ordinary telephone apparatus are made for this. According to the above description, however, the modulator of the transmitter is not suited to such low frequencies (the frequency characteristic falls off sharply below 300 c/s). Therefore at the telephone exchange at the beginning of the line to the transmitter a separate call apparatus is installed (*fig. 8*). This contains an auxiliary oscillator which is set in action by a relay reacting to 50 c/s, and which gives a signal on the line of 2 700 c/s. At the receiving end this signal, *via* a sharp cut-off filter (also included in the call apparatus), reaches a relay arrangement which now provides the ordinary call signal for the apparatus of the operator. At the same time the current source, switches and milliammeter for the direct currents with which the whole radio installation is operated are included in the call apparatus.

In conclusion it may be mentioned that the transmitter case contains a number of measuring instruments for testing the action of the whole and for detecting any defects. These instruments may be seen in fig. 6*a* on the middle panel; the upper row indicates the current in the different stages of the transmitter, to the left and right below the mains voltage supply and the heating current of the output stage are read off, while the centre meter can be connected at will to a number of

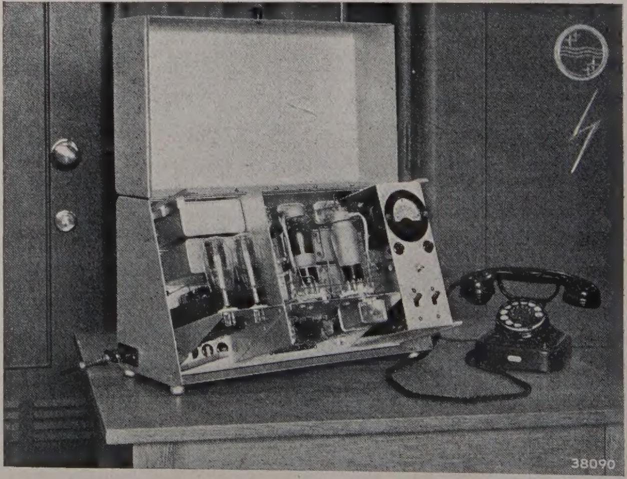

Fig. 8. The auxiliary apparatus in the telephone exchange. In this apparatus are the arrangements for switching on the installation from a distance and for calling the station.

points in the connections by means of the row of contacts to be seen below it. In the upper panel, see fig. 6*a*, a cathode ray tube is installed, to whose deflection plates the low-frequency voltage of the modulator and the high-frequency voltage of the aerial (taken from the aerial supply line led through the top of the case) are applied. On the screen of the tube the modulation characteristic [3]) is obtained in this way, which gives visual evidence of the depth of modulation and any deformation which may be present.

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[3]) See H. van Suchtelen, Philips techn. Rev. 3, 248, 1938.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabriken, Eindhoven (Holland), Kastanjelaan.

1520: Th. J. Weijers: Recente ontwikkelingen betreffende frequentiemodulatie (Recent developments in frequency modulation) (T. Ned. Rad. Genoot. **7**, 315-365, Oct. 1940).

A method was proposed by Armstrong in 1936 of obtaining radio reception with less interference due to noise by means of frequency modulation than is possible with amplitude modulation. In this lecture before the Netherlands Radio Association a theoretical discussion was given of the frequency modulation which in its main features follows the line developed by Carson and Fry in 1937, but which is somewhat simpler in various details. It is found that by making use of frequency modulation it is possible to improve the quality of the reproduction much more than is otherwise possible without disadvantage to the selectivity. In order to achieve these favourable results it is necessary to use frequency variations which are large with respect to the highest modulation frequency which is to be transmitted. It is, moreover, necessary to provide the receiver with an amplitude limiter.

1521: F. A. Kröger: ZnS, CdS, MnS en mengkristallen in het ternaire systeem ZnS-CdS-MnS. (ZnS, CdS, MnS and mixed crystals in the ternary system ZnS-CdS-MnS). (Chem. Wbl. **37**, 590-596, Nov. 1940.)

In this lecture given before the sections for Colloid Chemistry and Physical Chemistry of the Netherlands Chemical Society, the appearance of mixed crystals in the ternary system of ZnS-CdS-MnS was discussed on the basis of the phase theory. These investigations were carried out in connection with the fluorescent properties which such substances possess.

1522*: K. de Boer: Stereofonische geluidsweergave (Stereophonic sound reproduction) (diss. Delft Dec. 1940).

In this dissertation a survey is given of the investigations which have been carried out on the subject of three-dimensional hearing and three-dimensional reproduction of sound. In addition to the work of the author himself the results obtained by others are also discussed. The reader is referred to the articles which have already appeared on this subject in this periodical **4**, 316, 1939, **5**, 107 and 182, 1940.

1523: A. Bouwers: Een toestel voor de localiseering van projectielen (An apparatus for the localization of projectiles) (Ned. T. Geneesk. **84**, 4665-4667, Nov. 1940).

For a detailed description of this "bullet finder" the reader is referred to: Philips techn. Rev. **5**, 309, Nov. 1940.

1524: J. A. M. van Liempt and J. A. de Vriend: The fusing time of fuses. III (Z. Phys. **117**, 18-19, Dec. 1940) (Original in German).

Earlier investigations by the authors on the fusing time of thin fuses as dependent upon the short-circuit current are continued for the cases of different metals and alloys. The measurements were carried out with direct current (according to a method already described in this periodical **4**, 118, 1939) with wires of different shaped cross sections. As was to be expected theoretically the shape of the cross section of the wire has no effect on the fusing time.

1525: K. F. Niessen: Electrical field strength as a function of the energy consumed by the aerial II (Physica **7**, 897-908, Dec. 1940) (Original in German).

In continuation of **1510**, the vertical electrical field is calculated which is excited by a half wave length aerial at a point above a flat dry earth, for which a dielectric constant of 4 and a conductivity of 10^{-15} may be assumed. As in **1510** the calculations begin with the simple case where a mathematical dipole is situated at a distance of a half wave length above the earth. As in the earlier case a wave length of 30 m is used; the essential difference from the first publication consists in the fact that now the absolute value of the complex index of refraction is not large compared with unity, and the argument becomes practically equal to 45°, since the displacement current is large compared with the conduction current. The article ends with a comparison of the results found here with the values which would be obtained with the reflection formula. The striking point is not so much the improvement which the formula of Sommerfeld gives compared with the reflection formula, but particularly the fact that the field has now been successfully calculated from the total energy applied to the aerial, in which of course the energy is also included which is later absorbed by the earth.

1526: J. A. M. van Liempt and J. A. de Vriend: Pupil measurements with monochromatic light. (Physica **7**, 961-969, Dec. 1940) (Original in German).

The size of the pupil with monochromatic light has been measured as a function of the wave length and brightness with the help of Broca's pupilmeter constructed by Moss in the form of spectacles. With increasing wave length the pupil becomes larger, with a sudden increase at 5 700 to 5 900 Å. With mixed light there is no simple additivity in the size of the pupil. The summation law, as given by v. Kreveld for the density of photographic material under mixed light, and by Bouma for the subjective brightness of a mixed radiation, probably holds for the contraction of the pupil.

1528: J. D. Fast: Diffusie van gassen door metalen (Diffusion of gases through metals). (Chem. Wbl. **38**, 2-8 and 18-23, Jan. 1941).

A survey is given of the different mechanisms of diffusion which may be present in metals. In those cases where anything is known about the mechanism of the diffusion of the gases through metals, gas atoms (or ions) are found to diffuse through the interstices of the metal lattice. Upon the occurrence of a passage of gases through metal walls, however, it is not exclusively a question of this diffusion process, but also of two processes at the entrance surface and two at the exit surface. Upon transmission of gases through metals therefore there are different processes, each of which possesses its own activation energy. For different combinations of gas and metal and upon the use of not too thick walls, five different cases can also be realized, in each of which a different process determines the velocity of transmission. With the help of potential curves the different possibilities are represented diagrammatically. The writer then examines which of these cases occur in practice. Upon the diffusion of hydrogen through iron the greatest activation energy is necessary at the entrance surface for splitting the molecule into atoms. In the diffusion of hydrogen through palladium and of oxygen through nickel, however, the greatest energy is required at the exit surface for the recombination of the atoms to molecules, *i.e.* for exactly the opposite process. When hydrogen penetrates through copper walls it is a case in which the greatest activation energy is necessary for the diffusion of the hydrogen atoms (or ions) inside the metal.